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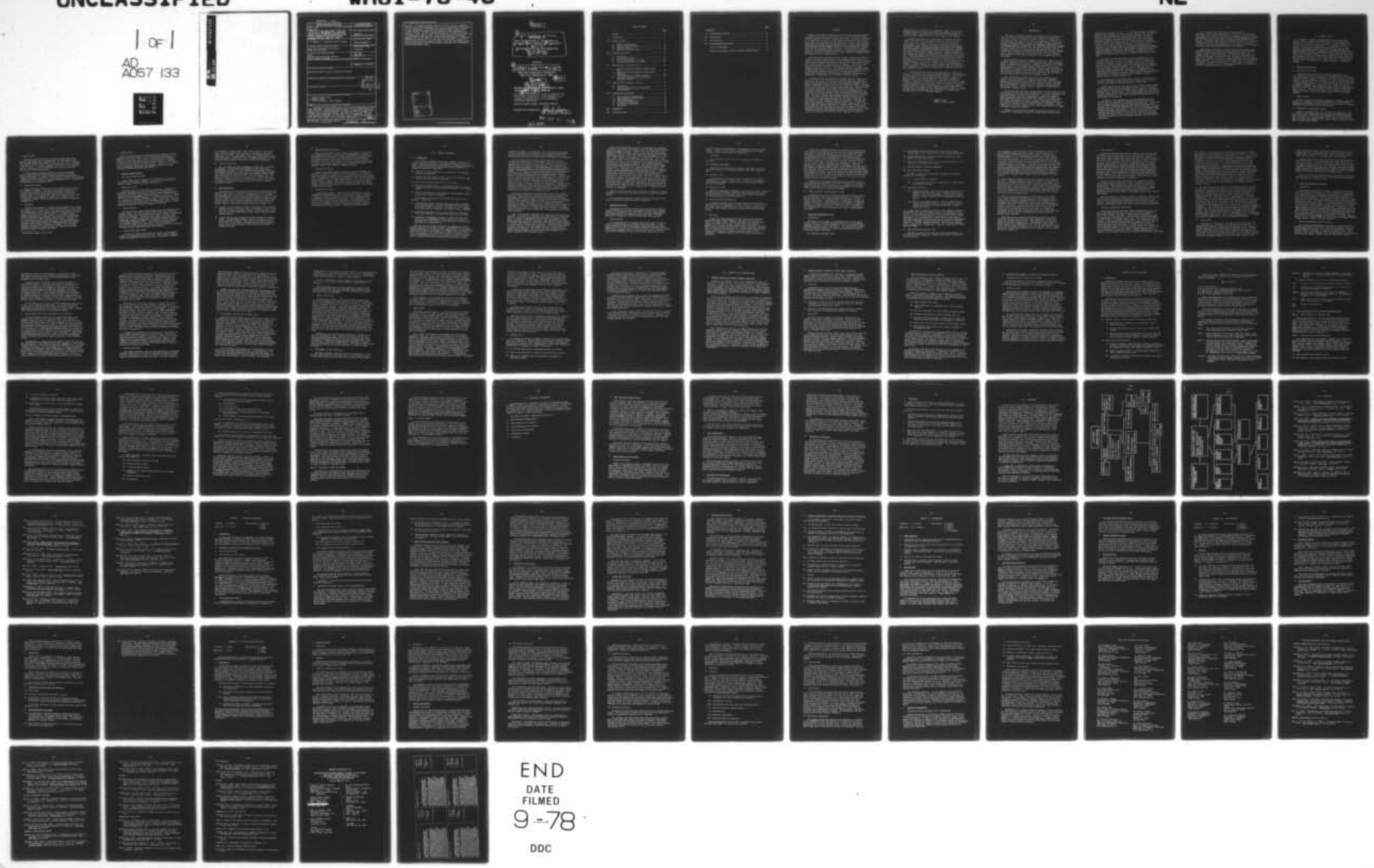

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A workshop was held on March 13-17, 1978 on a High Energy Benthic Boundary Layer Experiment. The meeting followed recognition of the importance of high speed currents at the deep ocean bed in eroding, transporting and depositing sediments and in producing bedforms. The importance of the turbulence and turbulent mixing processes in these regions was also emphasized. The workshop proposed an experiment with three main phases, detailed survey and site selection, short (3-day), and long (6-month) experimental (Cont. on back) cont'

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deployment of instrument packages designed to recover current, turbulence, optical, acoustic and photographic data. The site survey phase would involve not only hydrographic, echosounding and deep-tow survey but also recovery of undisturbed bottom samples and investigation of their properties in laboratory flumes. The short experiments would run at a high rate of data acquisition and get data on short term fluctuations of the floor and bed. The long experiments would have slower rates of data acquisition and employ in-situ processing and compaction of information from sensors. A cyclosonde profiling the lowermost 300 m of the water column with CTD, velocity and optical probes would be an essential feature. This and other aspects of the proposed program would require considerable engineering work in development of sea-bed instrument arrays.

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HELD AT THE
KEYSTONE CENTER FOR CONTINUING EDUCATION,
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EDITED BY

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FOREWORD

Despite the currently fashionable use of the word "interdisciplinary" to describe research projects, few such efforts are known among oceanographers studying the benthic boundary layer (BBL). In order to encourage discussions among the diverse groups interested in deep-sea BBL problems and to begin the coordination of experiments, the Office of Naval Research (Code 480) has recently sponsored two workshops. In March 1977 a group of investigators with ONR-supported projects met at the Naval Ocean Research and Development Activity (NORDA) in Bay St. Louis, Mississippi to define scientific and geographic areas of interest. A large group of investigators met for a more ambitious workshop at the Keystone Conference Center, Keystone, Colorado, from March 13 to 17, 1978. This report summarizes the deliberations of that second workshop.

The Navy's practical interest in the benthic boundary layer includes a gamut of questions regarding physical, geological, chemical and biological interactions with hardware as well as influences of these processes upon strategy. Somewhat less directly, the Navy is a producer of nuclear waste and is therefore concerned about its disposal. This concern converges with current interest in examining the feasibility of waste disposal beneath the sea floor. By weighing these Navy requirements and assessing the programs of other agencies (where there are several ongoing or potential BBL programs focussing on low energy environments), it seemed most appropriate for this workshop to consider BBL processes and experiments in high energy (i.e., strongly advective) regions.

It turns out that our knowledge of strongly advective regions is so meager that most of the questions a Navy planner might ask about them are exactly the same as the questions posed by scientists attempting to define a High Energy Benthic Boundary Layer Experiment (HEBBLE). It was quickly realized by the Keystone participants that we now have insufficient data to even decide where to conduct such an experiment. Despite decades of interest, which began in the 1950's with picture-taking and the theoretical prediction of the existence of strong counter-currents near the bottom, we now have perhaps a dozen current meter observations taken within 20 m of the seafloor and only half of them within the logarithmic layer. To anyone inquiring about sediment movement associated with a given current, we can reply that there are only two or three sets of observations in which sediment movement was monitored at the same time that currents in the logarithmic layer were measured. If anyone asks whether the existence of certain bedforms (dunes, ripples, furrows, etc.) can be taken as a simple indicator of a certain current regime, we can only answer that intuition says yes, but we really have no theoretical or modeling basis for predicting the magnitude and duration of the current required to produce a given bedform in deep-sea, cohesive sediments. In fact, we are so unsure of this that we don't know how to design the

sampling rate and duration of our experiment. Except for very small bedforms observed in current meter/camera deployments, we have no confidence that a given bedform will respond to a current that we can hope to measure in deployments of 3 days, 6 months or a lifetime.

Because we generally don't know whether the bedforms which now exist on the deep sea floor formed in response to past or present conditions, we must undertake theoretical or modeling studies of certain kinds of sediment/bottom current interaction to guide our experimental design. Because our intuition and limited data suggest the need for longer than usual deployments of sensors on the seafloor and, conversely, our knowledge of boundary layer phenomena indicates the need for high frequency sampling of short energetic "bursts", we must develop improved sensors and methods for conditional sampling of the environment, in-situ processing and denser packing of the recorded data. While these theoretical, laboratory and engineering studies are going on, we must consider the geographically limited state of our knowledge and continue exploratory studies of the distribution of high-energy BBL areas. These can be combined with short deployments of presently available sensors that should, ideally, feed back empirical results to modelers and theoreticians and help narrow the possibilities to be considered by engineers designing sensors, sampling plans, and data recording systems.

It is relatively easy to write such blueprints for progress; in fact, it is a conditioned response of program managers. The difficulties of doing the work can only be appreciated by reading on. This report points out many of the experimental uncertainties and logistical difficulties of doing deep-sea BBL work. Although it attempts to present a consensus of the Keystone conference, the report also provides a glimpse of the diverse opinions and "styles of science" that will have to be accommodated if truly cooperative work is to be done. Since we probably could not conduct all the proposed or desired experiments at one place and time without severely disturbing the processes of interest, the discussions and planning so profitably begun at Keystone must continue to be a part of future BBL programs.

THOMAS E. PYLE
Office of Naval Research

I. INTRODUCTION

The study of the bottom boundary of the ocean and its denizens has been the concern of marine geologists and biologists for many years. Initially, as with all branches of science, there was an emphasis on describing and cataloging the sea floor, its composition, form and biota. In recent years the study of seafloor photographs and multi-beam echo-sounding and side-scan sonar records has triggered a considerable interest in relating sediments and bedforms to the flow conditions in the boundary layer with which they interact. At the same time there has been an upsurge of interest in the energetics and metabolism of deep sea benthos in relation to conditions of flow, substrate and nutrient supply variability. There has also been concern on the part of several physical oceanographers to understand the dynamics of the boundary layer in the deep ocean.

This has been stimulated from several directions. Reports of super-adiabatic temperature gradients prompted detailed, near bottom investigation of temperature and salinity. Arguments relating deep sea boundary layers to those of the atmosphere have prompted speculation on the turbulent structure of the abyssal boundary layer, but as yet no direct measurements of turbulence have been made. *Munk's* (1966) "least strange" view of vertical mixing in the ocean being advection into the interior along density surfaces of water strongly mixed at the ocean boundaries has also prompted physical interest in boundary mixing.

Most of the marine boundary layer work with a dynamical flavor (whether from the standpoint of physical oceanography or sediment dynamics) has been carried out in shallow water. Here there have been many successes, notably *Bowden's* (1962 for example) work on turbulence using electromagnetic current meters, but also work on shear stresses derived from velocity profiles, boundary roughness, bedform migration and sediment transport theory.

By contrast there have been no measurements with fast-response current meters below 1500 m in the oceanic boundary layer. However instruments are now being developed to remedy this deficiency. There are already in existance suitable devices for measurement of temperature, salinity, light transmission, mean current speed and direction, for taking stereo photographs and samples of the bed. So many of the sensors required for a successful high energy benthic boundary layer experimental program are either in existence or in an advanced stage of development. There remains much to be done, however, in the area of data acquisition, <u>in-situ</u> processing, storage and telemetry.

Interest in the problems of boundary layers has been shown in the organization of meetings to discuss the problems and formulate plans,

particularly in the past few years. In 1974 NATO sponsored the Benthic Boundary Layer Conference at Les Arcs, France (*McCave*, 1976) in 1975 the Office of Naval Research Code 481 sponsored a workshop on primarily physical problems of the oceanic bottom boundary layer, in 1976 the 8th Liège Colloquium on Ocean Hydrodynamics had as its topic Bottom Turbulence (*Nihoul*, 1977) and since 1977 there has been a continuing benthic boundary layer biweekly seminar held at Woods Hole Oceanographic Institution and another meeting of principal investigators was co-sponsored by the ONR marine geology and physical oceanography branches at Bay St. Louis in March, 1977. In the field of shallow marine boundary layer and sediment transport the IDOE Office of the National Science Foundation sponsored a meeting on Shelf Sediment Dynamics at Vail in 1976 and this seems likely to lead to a large scale NSF program in the 1980's.

As a result of these meetings the view has developed that it is convenient and timely to look at two types of boundary layer study. One study would focus on areas of low energy (low flow speeds) where processes of chemical diffusion across the sediment water interface, nutrient inputs to the bottom, metabolic rates and biological responses would be the key parameters measured. This is LEBBLE an acronym for low energy benthic boundary layer experiment. The other type of experiment would be mounted in a high energy (thus HEBBLE) area and would examine the turbulent structure, shear stresses, mixing processes, intermittency of sediment transport, bedform genesis and possible organic controls of sea-bed erodibility.

So the purpose of the workshop reported here is to outline the scientific questions we have about such high energy areas of the deep sea floor and propose methods and programs to answer them.

Working groups were set up first of all to consider spatial aspects and temporal aspects of the measurement program. Then a set of disciplinary groups were formed to consider specific (physical, biological, geological etc.) problem areas. This report contains the contributions of these groups with a certain amount of editing and rewriting where we deemed such appropriate. The work is however substantially that of the participants at the meeting.

In essence it is concluded that the most profitable and cost-effective way of proceeding is by mounting experiments which would monitor physical and geological parameters simultaneously. Thus current and turbulence measurement should be combined with profiling of the boundary layer by CTD and transmissometer, acoustic profiling and photographic monitoring of bed behavior. In order to obtain maximum benefit from the experiments there should be detailed site surveys which would encompass sea bed parameters such as critical erosion shear stress, geotechnical properties and characteristics of the biota responsible for those properties as well as detailed morphology and bed roughness measurement.

It is suggested that there should be three phases to an experiment, a survey phase, deployment of a short (~3 day) experiment with a high rate of data collection, and subsequently a long (≳6 months) experiment with slower data collection and utilizing <u>in-situ</u> processing and a profiler system (cyclosonde) operating vertically upwards from the bed. In addition there should be laboratory programs to investigate turbulence structure over rough beds, critical erosion conditions of cohesive deep-sea materials <u>in-situ</u> and in the laboratory, and a program of numerical modeling studies of boundary layer behavior.

Some problems that were considered include the influence of the submarine structures in promoting biological activity and the effects of that activity on the sensors and the quantities sensed. For example a school of rat tailed fish could modify the turbulence field as well as modifying the hot wire probe. Increased benthic activity might occur yielding a locally more erodible substrate and consequently higher turbidity. It may be that we shall have to work on an underwater "scarecrow". We shall certainly have to consult with our biological colleagues and find some way of monitoring and perhaps discouraging the activity of organisms around our experiments.

II. SPATIAL ASPECTS

It is easy to confuse the establishment of priorities among spatial scales of boundary layer phenomena to be investigated with decisions about specific sites to be examined. In this section we attempt to look at the various aspects of the spatial variability of boundary layers and leave the matter of site selection to a later section. Nevertheless it must be noted that we are concerned with deep sea high energy boundary layers and that, generally, means deep western boundary currents. Furthermore we should note that most information on currents and bedforms in such systems comes from the western North Atlantic however the western South Atlantic, western Pacific and western sides of the basins in the Indian Ocean have analogous systems which are less well known in even a descriptive sense. We should be forgiven then if the western North Atlantic appears to dominate our thoughts.

A. Scales of Bed Features

1. Crag and Tail Features

These lineations on the bed are probably erosional in origin (c.f. deflation patterns) (see *Heezen and Hollister*, 1964, figs. 5 and 6 for photographs). They are typically a few millimeters to centimeters in height and have spacings of centimeters to tens of centimeters. They appear to be distributed over relatively flat beds and would constitute a uniform boundary roughness. For simplicity of flow structure and ease of laboratory modeling this type of bed would probably be best for deployment of HEBBLE. Recent sampling of *Gage* (1977) also suggests that the biota of such areas is reasonably uniform in spatial distribution. Gage's study of a crag and tail bottom at 2875 meters in the Rockall Trough also reveals a surprisingly high density of macrofauna (mean = $1853/m^2$).

2. Ripples in Mud

Ripples are locally distributed, especially in furrows. They have heights of a centimeter or two and wavelengths of 10-20 centimeters. Large fields of abyssal mud ripples have not yet been found so deployment of HEBBLE on these forms is not a first priority.

3. Triangular or Longitudinal Ripples

Heezen and Hollister (1964, fig. 10) and *Flood* (1978, fig. 2.25) record these from Mozambique Abyssal Plain and the Blake-Bahama Ridge area respectively. Flood gives ripple dimensions of 10-20 centimeters high, 1-5 meters apart and 2-10 meters long. These are known over a deep-tow traverse 20 kilometers long. There is thus at least one large area containing these bedforms.

4. Small Furrows

Furrows have been found or are suspected in many areas where currents flow rapidly over a sediment bed. The best knwon set are from the Blake-Bahama Outer Ridge (*Hollister et al.*, 1974). They are a few meters wide and about a meter deep spaced tens to a few hundreds of meters apart. It has been suggested that they owe their spacing to helical circulation in the bottom mixed layer which is typically a few tens to a hundred meters thick.

At some stage an experiment should be mounted to determine whether there is helical circulation present; this will require accurate deployment of a number of sensor arrays precisely located in a region about 100 m across flow by 1 km downflow. Because of positioning difficulty an area of greater topographic homogeneity (i.e. crag and tail) should probably be investigated first.

5. Large-scale Furrows

Large furrows have depths of up to 20 m, widths of 50 to 150 m and spacings of 50-200 m. They may be associated with helical flow in the bottom mixed layer and probably also contain significant secondary flows within the furrows. The sea bed in this type of area is clearly very rough and is probably not suitable for the types of instrument arrays envisaged in Section III. However in any assessment of boundary layer flow structure, such an area should have a high priority.

6. Mud Waves

Sediment waves composed of silt/clay with wavelengths of 1 to 5 km and heights of 10 to 50 m are now known from many areas. *Flood* (1978) has suggested that in-phase waves (lee waves) may be present over them and be responsible for the spatial variation in deposition rate which maintains them and causes their migration. In a second stage of HEBBLEs, investigation of boundary layer structure and sediment flux over mud waves will probably assume a high priority. But, as with the investigation of small scale furrows, it will be necessary to accurately deploy several monitoring arrays, preferably with vertical profiles of water properties from a bottom moored CTD "cyclosonde"[1] along the flow path over a distance of a few km. It may be more profitable initially to conduct surface ship operations and deploy simpler instrument packages on mud waves.

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[1] See details on pages 13 and 20-21.

7. Sediment Drifts

Many of the bedform scales listed above are superimposed on large sediment drifts with lengths of up to thousands of kilometers and heights of a kilometer. Most of these occur under and are thought to be constructed by high energy flows in western boundary circulation. A summary of their location and characteristics is given by *Hollister, Flood and McCave* (1978) for the North Atlantic. This scale is attacked best by large-scale hydrographic and geological studies with deep drilling to address paleocirculation models.

B. Scales of Flow Structures

1. Inner Layer Turbulence Scale

A logarithmic layer of perhaps 2 m in thickness is anticipated. The genesis of small-scale roughness (crag and tail) and ripples is directly related to events occurring in this layer.

2. Mixed Layer Scale

The mixed layer is of 10 to 100 m in thickness. It appears to correspond reasonably well with the thickness of an Ekman layer in which the layer height is defined by the point where turbulent kinetic energy goes to zero, a height expressed by $Au_*/f\ (1 + N_0^2/f^2)^{1/4}$, where where N_0 is Brunt-Väisälä frequency, f is the Coriolis parameter and A is a constant ~1 (*Weatherly and Martin*, 1978). Within this scale occur the motions which are thought to be responsible for furrows. Internal waves may form on the upper surface of the mixed layer and may control patterns of deposition leading to formation of mud waves.

3. Coherence Scales

One objective of a long term experiment would be to measure fluxes through a "box". For this to yield a valid picture there should be coherence between the stations defining the box in velocity and suspended material concentration. We have little to guide us on likely time scales, but in studies on the shelf, under steady wind-driven flow, considerable changes in temperature and nephels are found within a day or two (*Pak and Zaneveld*, 1977). It may thus not be safe to assume that coherent distances are long, and it is felt that spacing of stations 2 km across the flow and <10 km along the flow would be necessary for coherent data yielding meaningful flux estimates.

4. Scales Greater Than 100 km

On scales of 100 km or more there are changes in the suspended sediment load along the direction of flow. These reflect changes in erosion and deposition along the flow path. Also there are changes

in the density of bottom water. Some layers of water can be traced using T/S characteristics over hundreds to thousands of kilometers. These scales of change, like those of the major sediment drifts are beyond the scope of a single HEBBLE. They will be approached by broad scale hydrographic studies and a number of HEBBLE deployments to yield information about regional variation in processes and properties.

5. Vertical Variability

Next to the sea bed there is generally a mixed layer of 10-100 m in thickness. This may have been generated at some time before measurements are taken in it so its height may not be well related to the processes (u_*) active at that time. CTD and nephelometer profiles have shown a multiple layered structure with probable "fossil" mixed layers overlying the bottom one. This vertical variability in T, S, suspended material concentration and properties, currents and turbulence and in Radon-222 needs to be examined with regard to the process of shedding of mixed water lenses into the interior from upstream topographic elements.

C. Deep Ocean Mixing

The existence of "fossil" mixed layers above the bottom mixed layer indicates some transfer of boundary layer properties into the interior. The long range goal of a portion of the HEBBLE effort is to attempt some understanding of deep ocean mixing and turbulence. Vertical, cross-isopycnal, mixing in the deep ocean appears dominated by bottom mixing, yet the relative roles of mixing and and advection along sloping isopycnal surfaces and the resultant boundary-produced vertical flux are unclear. Sites at which these relative roles can be isolated are:

(1) A region of nearly spatially uniform topography beneath a western boundary current. The Scotian Rise is an example of such a region which has the added advantage of having a water mass tracer in the form of a potential temperature/salinity anomaly (Denmark Straits Overflow Water).

(2) A region with an abrupt topographic change upstream of a uniform region. The New England Seamount Chain is an example of such an abrupt topographic feature. The techniques and instrumentation to be used are a CTD with a nephelometer and acoustic navigation within a net of bottom-mounted current meter and temperature measuring moorings.

D. Spatial Variations in Biota

There is an hypothesis, that remains to be tested in the deep sea, which maintains that the variations in suspended material loading of the nepheloid layer may not only depend on variations in bottom current velocity but may also reflect the differing activity of benthos in resuspending sediment and making it more easily erodible by surface reworking. There are thus a number of questions concerning the spatial distribution of benthic organisms and their activity which need to be answered. These can be posed at a variety of scales.

1. Large-Scale Patterns

How does the regional spatial pattern of erosion, transport, and deposition of sediments correspond with the abundances of particular functional groups of organisms (e.g., as analyzed by *Jumars and Fauchald*, 1977)? Do suspension feeders become abundant in areas of high suspended load and possibly play a large bio-depositional role? Are the functional groups found in erosional environments likely to accelerate or impede erosion? These questions can be addressed by box coring from surface vessels and from detailed analysis of bottom photographs, many thousands of which have been taken.

2. Small-Scale Patterns

Do functional groups of organisms vary in abundance with local topography and hydrodynamics, e.g., in troughs vs. crests of mud waves or inside vs. outside of erosional furrows? This question can best be addressed via accurately located coring using a submersible or a profile camera placed across the interface. It is important to note that accurate answers to these questions will allow the judicious location of experiments to reveal the spatial and temporal facets of those biological processes unique to high-energy deep-sea bottoms.

III. TEMPORAL VARIABILITY

A. Introduction

The temporal variability group posed a number of questions that a High Energy Benthic Boundary Layer Experiment should endeavor to answer. These questions were acknowledged to be somewhat site specific and to focus the discussion, the Scotian Rise was considered in framing the questions. These were:

(1) What are the flow conditions (e.g. critical u_*) for sediment erosion and deposition?

(2) How does the flow condition modify the bed and conversely what is the effect of bedforms on the flow?

(3) What is the thickness and structure of the BBL?

(4) What are the characteristics of the nepheloid layer, how much suspended material is being transported and what is its vertical flux?

(5) What are the effects of soil properties, with biological modification on the erosion of sediment?

The answers to these questions involved three time scales of experiment. These were:

(1) A detailed site survey by deeply towed echo sounder, side-scan sonar and photography. Box cores for laboratory flume studies on a natural "rough" bed would be taken and a number of <u>in-situ</u> flume experiments on erodibility of sediment would be conducted.

(2) A three-day experiment to try to characterize the inner scale (near wall turbulence) with outer scale (mean flow) variables.

(3) A six-month long <u>in-situ</u> experiment to study the natural flow conditions, the flow-sediment interaction and its variability. The objectives, measurements and the time scales of each of the experiments is discussed below.

The site would be carefully surveyed with <u>in-situ</u> geotechnical sediment properties (vane shear strength, penetrometer and pore water pressure measurements) being taken in conjunction with an inverted-flume experiment to discover the threshold for sediment motion and erosion rates. Photographs of the bottom would be taken to identify the epifauna including megafauna--this is to estimate the kind of biological activity expected--and stereo photographs would also show surface

roughness and large (>2 cm) epifauna. Box cores would also be taken to allow the infauna to be sampled to aid in estimating bioturbation, biological binding or pelletization of the sediment as well as to measure physical/chemical and radiochemical properties of the sediments.

Box cores from the site survey would be put in a flume for "ground-truth" measurements of geotechnical properties, binding vs. disaggregating biological processes, and a measure of turbulent flow would be made over a nearly natural rough bed. The objectives of the geotechnical studies are to provide parameters to relate critical erosion stress measurements to the biological aspects resistance to erosion. Stabilizing vs. de-stabilizing processes of bioturbation and binding will be estimated by studying the infauna (micro, meio and macro organisms), epifauna, quantity of binding agents in surface sediment (mucopolysaccharides), and aggregate structure. Finally flow over a rough bed (the box core sample or more likely a replica of its surface) will be studied to determine the microtopographic effects on stress profiles, effects of roughness spacing on boundary layer structure, stress co-spectra, probability structures of Reynolds stress tensor, dissipation and fine structure and intermittancy--generation processes of Reynolds stress over rough boundaries. Sediment motion (initiation and erosion rate constant) would be determined using a preserved box core surface in a laboratory flume.

A three-day experiment has been devised to tell us how closely we have to measure the flow. The measurement objectives include flow properties, geotechnical properties, and topographical properties. Three-dimensional velocity means, fluctuations, and Reynolds stresses measured with a sampling frequency of 50 Hz for one hour during various phases of the tidal cycle and at vertical separations capable of resolving the height of the BBL plus its vertical structure and temporal variability are required. Detailed temperature, salinity and light transmission, both mean and fluctuations in the 30 Hz to 1 Hz temporal range, are desirable to test whether they can be parameterized by outer scale variables.

Most of the three-day experiment can be done with existing instrumentation. The purpose of a separate short experiment is to make high data-rate turbulence measurements less necessary on long-term experiments. We need to establish inner-outer scale relationships in which easily measurable outer scale parameters could suffice for both scales. In addition, high frequency data will allow a rational sampling strategy to be developed for the six-month experiment. Laboratory measurements on surface replicas of box core samples can also be instructive in defining flow conditions. CTD, optical and radon profiles should be taken repeatedly during the three day experiment, preferably in a pattern upstream of the instrument array.

The six-month experiment has need of three sampling strategies: continuous low frequency measurements, data from high frequency sensors processed in situ and stored in compact form, and conditional burst sampling for event recording. The continuous samples include current, temperature, salinity, light transmission and photographs of the bed. These could be made at a few points from fixed instruments but it was felt a finer vertical scale measurement was important. Thus, these measurements would be made from a cyclosonde that would make a vertical excursion every hour or two recording at 15 cm spacing over 200 to 300 m above bottom. The cyclosonde would sit at the bottom recording at 10 minute intervals between excursions. The cable on which it rides would contain a VACM at the top. A second instrument array in the lowermost 1 to 2 m would be a tripod with stereo TV cameras, vector velocity sensors, nephelometers, and temperature sensors. A downward looking echo sounder would monitor bedform height changes and an upward looking acoustic backscatter system would make profiles of particulates. The velocity systems would record on refreshable buffer memory and in general run 30 minutes/day to save battery power. The turbulent statistical measurements and the Reynolds stress average and peak values would be recorded each tidal cycle. The TV camera would compare one image to another and event-trigger the other measurements on a significant change in image. Then all systems would record continuously for 10 minutes at a 1 Hz sample rate. A single such system at a site is envisaged.

Finally, a sediment trap array at each site is required to provide estimates of fall out rate and yield samples for location of possible tracers.

The following sections give further details and thoughts on the survey, three-day and six-month seabed experiments.

B. Detailed Site Survey

After large area surface ship surveys have thoroughly delineated a large (100's of km on a side) physiographic province that contains evidence of being current swept and after a few dozen camera stations have identified fields of apparently active bed forms, the HEBBLE program will progress into sets of detailed near bottom surveys.

1. Deep-Tow Survey

It is envisaged that the primary survey vehicle will be a deeply towed instrument package carrying narrow beam echosounder, 3.5 kHz sub-bottom profiler, stereo photographic cameras and side-scan sonar. Signals from the latter may be recorded on tape for subsequent processing. The detailed topographic survey of a site on the order of 100 km on a side would be achieved with this system and the stereo pairs of the

sea bed would allow photogrammetric determination of bottom roughness scales. In addition the nature and spatial variability of organic activity would be assessed from the photographs.

2. Box Cores

It is necessary for box cores to be obtained for a number of purposes:

(a) Turbulence experiments.

Replicas of the surface would be made so that models of the sea bed can be inserted in a flume for turbulence work over a "natural" bed.

(b) Biological work.

Determination of the faunal content and effects of the fauna on sediment structure would be carried out. In particular properties (e.g. grain size, organic carbon content) relating to bed stability would be investigated.

(c) Geotechnical work.

Profiles of geotechnical properties with depth, e.g. shear strength and water content, Atterberg limits grain size and mineralogy, which will be determined for correlation with both biological, erodibility and measured in situ geotechnical properties.

(d) Critical erosion determination.

A specially designed system (already existing at the University of Rhode Island) will be necessary to provide samples to be inserted in a salt-water flume for determination of critical erosion shear stress and erosion rate constant (variation of mass erosion rate with shear stress).

3. Sea Flume

A device for making in-situ critical erosion shear velocities called "sea flume" has been designed, fabricated and deployed by *Young and Southard* (1978). Such an instrument is an essential component of any deep ocean benthic boundary layer investigation. However, for the latter problem several modifications need to be made. These involve providing the capability of making simultaneous measurements of geotechnical properties, such as vane shear strength in the surface few millimeters of sediment and taking a sample of the population of organisms responsible for any change in geotechnical properties.

A vane shear strength measuring device should be mounted near the test section of the flume and used to correlate the gross geotechnical properties of the bottom sediment with critical erosion velocities. In addition, the physical and biological processes that give rise to the measured surface shear strength, hence, the measured critical erosion velocities, must be elucidated and to do this an assessment of the spatial structure of the bed material and the organisms that live within it must be made. Therefore, the capability of taking a short box core from the side of sea flume must be developed. Also the possibility of using an interface camera at the edge of the test section and running an ultrasonic device along a track inside the flume before and after the critical shear velocity measurements have been made should be considered seriously. An accurate means of measuring flow and boundary shear stress in sea flume needs to be developed, as does an optical sensor to determine the onset of erosion and change in erosion rate with time. Ideally not only the critical erosion stress but also the erosion rate constant should be determined in situ.

Deployment of the in situ flume should be at a number of points within the surveyed area so as to provide an estimate of the degree of variability of the critical erosion stress. Consideration should be given to deployment of the flume using a submersible so that several sites within a restricted area can be examined.

4. Nephel Properties and Hydrographic Survey

Calibration of the optical sensors against filtered water samples must be undertaken prior to the six month deployment. In addition the deployment area will need hydrographic surveys before as well as during the experiment. Calibration will be undertaken by running the optical sensors with a rosette sampler to obtain samples of suspended material. In addition it would be valuable to obtain an estimate of the settling velocity distribution of the particles in suspension to aid interpretation of the data from the two types of transmissometers to be used.

C. Short Term Experiments (3 day)

1. Introduction

The purpose of this stage of the proposed study of high energy boundary layers is to provide baseline information to guide sampling strategies in time for longer deployments and to provide high frequency turbulence data from close to the sea bed. This information will be used in the specific design of a longer term experiment which would be the next stage of the study.

The three-day experiment would:

(a) provide high frequency measurements of the velocity field, density field, optical properties and stereo bottom photographys,

(b) provide detailed CTD and optical profiles together with water samples for suspended sediment,

(c) serve as an engineering trial for the various subsystems to be used in the next stage of the study.

2. General Outline of Three-Day Experiment

(a) Data acquisition systems

In order to carry out the three-day experiment the following systems will be necessary:

(i) a deep submergence vehicle

(ii) a bottom-mounted platform carrying sensors, cameras, power and recording capacity.

(b) Measurement objectives

(i) In-situ parameters: mean and fluctuating (turbulent) components by hot wire and acoustic velocity sensors, temperature, light beam transmission, acoustic backscattering particle sensing, time lapse stereo photographs, interface camera.

(ii) Physical oceanographic survey: CTD casts, mean velocity survey, light beam transmission, water samples filtered for nephels and processed for Radon measurement, low-angle oblique photographs.

(c) Further detail on particular aspects of the turbulence, physical oceanography and radon measurements comprise the remainder of this section. To save duplication, details of the transmissometer systems are not given here but are given in the next section on the six month experiment. It is envisaged that the same type of system would be used both in situ and on profiling devices (cyclosonde and hydrographic lowerings). The CTD, deep-sea cameras and filtration for suspended material are standard techniques/apparatus. The interface camera to look at changes in the sediment water interface is described by *Rhoads and Young* (1970).

3. Flow Variations--Turbulence Work

The need for deep sea flow and bottom stress measurements up to the 10-100 Hz range (sampled for several tidal cycles) is motivated by several facts:

(a) No complete turbulence-spectra from the dissipation range to the Brunt-Väisälä-frequency are known presently from any high or low energy deep sea sites with smooth or rough bottom. For flows with a Reynolds number of $\sim 10^4$, the dissipation range of the energy density spectrum starts at 30 Hz. It is necessary to obtain at least one set of reliable three-dimensional flow data to demonstrate that available laboratory turbulence results from two-dimensional flows can be utilized in modeling deep-sea turbulence. Deviations from the data of equilibrium laboratory boundary layers might be expected for deep sea flows due to a variety of in-situ driving forces such as geothermal heat flux, density-stratification, propagation and breaking of internal waves, possible helical (three-dimensional) mean flow structures absent in flumes (not to be compared with flume-wall effects) accelerated and decelerated flows (density currents, tides), surface flow and planetary (Coriolis) effects.

(b) Since laboratory studies have shown that boundary layer (and also free shear) turbulence contains large scale coherent structures and is governed by intermittent Reynolds stress production, the scaling of the ejection-sweep cycle (used in the sense of lab researchers) for smooth and rough flows is under investigation. Again, a set of deep sea Reynolds stress and direct bottom stress measurements with sensors comparable in size to the Kolmogoroff microscale would provide us with information as to how far laboratory results of the burst-scaling (intensity, period, statistics) apply to deep sea flows.

(c) The size and frequency-response of metal-clad hot wire sensors (4 mm sensing length, 0.4 mm diameter) and of flush-mounted bottom stress probes (foil with 5 mm base length, 0.2 mm thickness) allow us to measure flow dynamics immediately at and in the millimeter and centimeter range above the sea bed in the velocity range approximately 1 mm/sec to 30 cm/sec. Friction velocity (u_*) as well as small-scale related temporal and spatial boundary layer structure thus can be resolved in scales obtainable by no other sensor in a 10,000 psi-environment and will deliver input data not only for physical models of the BBL but also for fluxes of sediments and solvents across the sediment-water interface.

Metal-clad hot wire anemometry extends the observation range of rotor type, acoustic travel time and other medium size oceanic flow sensors to the high-frequency scale. Intercalibrations in laboratory flows will precede the in-situ cast. The turbulence sensor array should consist of one bottom stress probe and two x-probes (oriented in the x-z and y-z plane) at heights of 1, 3, 10, 30, 100 cm above a smooth mud bed and (without bottom stress probe) at heights of 10, 20, 50 and 100 cm for a rough bed.

4. Flow Parameters

Besides measuring the high frequency velocity flucuations in the lower meter of the boundary layer, it is also important to investigate the velocity field at increased distances from the bed in order to resolve the larger length scales in the flow, and to observe the spatial variability of the velocity fluctuations and Reynolds stresses in the vertical. Three-dimensional velocity measurements taken with volume averaging sensors such as the acoustic travel time sensor or electromagnetic current meter at a number of levels above the bottom (50 cm, 100 cm, 200 cm and 400 cm) would provide data on the scales of turbulence greater than 30 cm. These data would also provide mean velocity profiles in addition to profiles of the turbulent kinetic energy and Reynolds stress. These measurements, coupled with the high frequency hot wire anemometry data would not only give a detailed picture of the velocity field in the boundary layer, but would also serve as an intercomparison of velocity measurement techniques.

The use of fast response thermistors in conjunction with the velocity measurements is required in order to observe the effects of the stability of the density field on the velocity structure of the boundary layer. These temperature measurements would show if there is any correlation between the passage of water parcels of different temperature and high stress events. The spatial resolution of temperature in the vertical should be comparable to that of the velocity measurements.

From the viewpoint of sediment transport, it would be useful to have a time series of light beam transmission in the lower meter in order to look for correlations between suspended sediment concentration and velocity. The transmissometer will sample at a sufficient frequency to see the relationships between high stress events and suspended materials.

5. Physical Oceanographic Measurements

During the three-day experiment, physical measurements are to be made to determine the vertical structure and temporal variability of the benthic boundary layer (BBL). Parameters to be measured are $\bar{\underset{\sim}{v}}(z,t)$, $\bar{C}(z,t)$, $\bar{T}(z,t)$ and $\bar{S}(z,t)$, where overbars denote time averages, z is height above the bottom and t is time. Here $\underset{\sim}{v}$ is the horizontal velocity vector, C is sediment concentration, T is temperature and S is salinity. The time averaging interval for $\underset{\sim}{v}$ should be of the order of minutes and the vertical spacing of the measurements sufficient to resolve and define the inner region of the BBL (and hence to infer the bottom shear stress) as well as the outer region. The time average for C similarly should be of the order of minutes and the vertical spacing sufficient to determine vertical profiles unambiguously. The vertical T and S structure can be easily obtained with profiling instruments.

The frequency of profiling should be initially of the order of minutes and can be very likely reduced to once per hour or longer if the vertical variability of the BBL proves to be sufficiently slow. Not only in the BBL, which is expected to be about 100 m thick, are these parameters to be measured, but also in the water immediately above this layer to determine its variability as well. Thus measurements should be made to 200-300 m above the bottom. For these measurements existing and field tested instrumentation is to be used (e.g., VACM's, profiling transmissometer, CTD's/STD's). Hydrographic transects cross stream and up/down stream with emphasis on the lowest 300 m are to be taken: the length of these transects are to be 10 to 50 km and the transects are to be made at the beginning and end of the experiment. Bottom surveys about each mooring and bottom mounted instrument are to be made to identify natural and artificial bottom features which may affect the flow. A submersible would prove most helpful for this; it could also be used to relocate instruments in more suitable areas. Time sequence bottom photographs, similar to those obtainable with M. Wimbush's tripod apparatus, are to be taken to detect bed form migration and suspended sediment transport events.

Not only is the benthic climate to be determined during the three-day experiment but new instruments, as they become available, which may be used for the six-month experiment are to be field tested and their data intercompared with each other and other standard instruments. In particular, the BASS system and cyclesonde could be used as well as instrument packages using Gust's hot wire velocity probes and bottom stress gauges. It is important that the high response (up to 50 Hz) velocity probes be used to obtain time series of the turbulent fluctuations at several heights in the inner region of the BBL during this experiment over several tidal cycles. At present we do not know how the Reynolds stresses vary in time and height over a tidal cycle. For the six month experiment it will be impractical to sample these high response instruments continuously. The three-day experiment should reveal practical sampling schemes. The three-day experiment is also important in that it should produce a data set which should enable us to estimate important inner variables (e.g. bottom stress, level of intermittency, etc.) from knowing outer variables (geostrophic current, bottom roughness, etc.). It should also provide a definitive data set for modeling BBL phenomena.

6. Excess Radon

Radon-222 is a radioactive, noble gas with a four-day half life which is dissolved in sea water and in the pore waters below the sediment-water interface. Because the concentration of its radioactive parent, radium-226, is very much higher in sediments than in the water column, radon dissolved in pore waters diffuses out into the water of the benthic boundary layer. This excess radon from the sediments serves as a tracer of mixing proceses near the bottom and, in general, the more intense the mixing the higher into the water column it may be found.

Within those bottom layers, well mixed in temperature and salinity, ranging from tens to hundreds of meters thick, the top of the isothermal layer coincides with the upper limit of well-mixed excess radon above which there is a sharp decrease in this tracer.

Vertical profiles of excess radon taken in the Western Boundary Undercurrent (WBUC) on the Blake-Bahama Outer Ridge display well-mixed excess radon up to two or three hundred meters above the bottom. By comparison excess radon above the adjacent Hatteras Abyssal Plain is generally capped at the top of the isothermal layer tens of meters above the bottom. Fitting these data to a model of vertical mixing yields vertical eddy diffusivities of hundreds of cm^2/sec in the WBUC versus on the order of 10 cm^2/sec in the abyssal plain.

The use of this tracer during both the site survey and three-day experiment phases of HEBBLE can aid in describing the mixing regime as a function of both time and space.

D. Long Term Experiments (6 months)

1. Introduction

This stage of the study is to monitor processes over the longer time scale thought to be important to many boundary layer processes. It is anticipated that the flow may be intermittent on a rather long time scale and six months is probably a minimum period necessary to look for this intermittency. The experiment would be deployed in the same site as the three-day experiment(s) so the basic station variables would be well known. Two types of instrument array would be needed to monitor the whole boundary layer. A cyclosonde carrying a CTD, velocity and optical probes would profile the lower 300 m of the water column. A bottom mounted array would take measurements of turbulence, velocity, nephels (optically and by upward-looking acoustic backscattering), bed-forms (through echosounder, TV and stereo photography) and temperature both in the water column and in the bed to obtain geothermal heat flux. The instruments would be run by a microprocessor which would also process much of the data *in situ* to compress it for storage. Sampling would be both on a regular basis and also through event triggers operated through velocity, nephel or TV camera sensors.

2. Profiling Measurements with Cyclosonde

For a complete understanding of the overall vertical structure of the BBL, long duration (1/4-1 year) profiling is required. Since the Brunt-Väisälä period at depth is >2 hours, an hourly profile of each parameter should be adequate. Parameters of importance are: vector velocity, light beam transmission (for suspended sediment concentration), temperature and density. Profiles should be taken with a vertical

resolution of ~15 cm and should extend to an elevation of ~300 m. These vertical scales would be decided by analyzing pivotal data from the region. The vertical extent of the profiles should at least encompass the bottom mixed layer.

We propose that a "cyclosonde" type vehicle be developed to record these profiles. Such a device has several advantages. Only one sensor is needed for each parameter and hence sensor inter-calibration difficulties are eliminated. Much higher vertical resolutions are possible than with fixed level sensors. Also, this instrument lends itself to very flexible programming; for example, a relatively rapid (i.e., coarse resolution) ascent could be followed by a descent whose rate would be varied according to the gradients observed on the ascent. By adding a camera, zoom sequences of sea bed photos could be obtained on each cycle. An array of these "cyclosonde" moorings should be deployed to monitor the horizontal variations.

At the summit of one of these cyclosonde moorings we would propose to add a vector averaging current meter. The current meter would record (every 10 minutes) the flow conditions outside the BBL. An independent mooring would be used to deploy a vertical suite of sediment traps, perhaps with adjacent recording transmissometer.

3. High Frequency-Small Scale Measurements by Bottom Array

The fluid-sediment interactions that modify bed forms or erode sediment may be infrequent but important events. From the fluid dynamics standpoint, little is known about the actual turbulent flow structure during such events over rough topography and it is not certain that laboratory flume work will be able to resolve these undertainties since the Reynolds number and scales in the sea cannot be duplicated in the laboratory. Yet, turbulence measurements generate a lot of data due to the requirement of rapid sampling to obtain the velocity fluctuations that characterize the flow. Much the same can be said for fluctuations in suspended matter concentrations. Thus, an experiment to measure the flow and nepheloid layer character during a rare event affecting bed forms or producing erosion must compress the data to a more manageable volume.

Two approaches are possible and both should be used. The first is data compression by pre-processing the raw data <u>in-situ</u> and only recording derived quantities. The second is conditional sampling for a short time triggered by an event. The event trigger must be automatically adjusted to prevent over-triggering or under-triggering and a simple automatic-gain-control type program in which the threshold for triggering is raised after an event occurs and decays slowly with time, should ensure uniform event triggering over the deployment period (6 months). In order to capture the onset of an event a buffer storage system will be necessary.

The sensors required to measure the flow and suspended sediment during an event are vector velocimeters, temperature sensors and nephelometers in a bottom-mounted array. These should sample the flow at a scale capable of resolving the dynamically significant turbulent eddies. If it is felt that dissipation scales must be resolved, 50 Hz samples from 2 mm sensors would be required. Thirty cm is about the lower limit of eddy size carrying significant energy at distances of 50 cm or greater from the bottom and these can be sampled in a 15 cm sensor at 1 Hz. In any case, the samples of velocity, temperature, and sediment concentration (optically) should be made daily for 30 minutes to represent sub-tidal periods of variability in the flow. Each day, a processed turbulence spectrum, if the 50 Hz sample is used, or mean and extreme Reynolds stress, heat flux, and sediment flux should be generated. These derived quantities would be computed by microprocessor during the daily measurement and recorded.

The fixed array of velocity sensors, etc. should also contain bed form monitoring and recording equipment. Stereo pairs of TV and photographic cameras are suggested to obtain images of the bed and an acoustic profiler can measure bed form heights. At intervals, perhaps 10 minutes, a TV picture, velocity and light transmission measurement would be taken and compared to the previous picture, velocity, or value to derive a trigger signal. A change in any one of these greater than the threshold would trigger a 10 minute burst of velocity, temperature and light measurements to be made and recorded. The TV camera images and acoustic profile would also be recorded. An upward looking acoustic backscatter sensor to profile suspended particulate scatterers through the mixed layer would be turned on to monitor the vertical distribution of sediment concentration. This burst of measurements could be repeated although the threshold would be raised. The images would be taken and recorded at 10 minute intervals for six hours.

Although not an element of the fixed array, the cyclosonde can also provide conditional samples in the burst mode. Since in its parked position at the bottom of its travel it measures and records temperature, density, sediment concentration and velocity, it can trigger itself on sudden changes in any of these variables. When triggered, it should perform and cycle immediately and continue as long as the threshold is exceeded. This will provide the vertical structure that can define the event.

4. Scale of Bed Forms

The 6-month experiment, which includes measurements of suspended sediment, particle flux, and physical conditions in the lower mixed layer and particularly the bottom 10-20 meters, will have a primary interest in bed forms of a variety of scales. The major emphasis of

these experiments should be directed towards the smaller bed features having horizontal scales from millimeters to approximately 30 cm. These bed forms result from high-energy flows and/or benthic activity acting over time scales much shorter than the duration of the experiment and could be expected to respond quickly to any high energy events and/or benthic activity that occurs. Further their size is such that they could be observed from a stationary bottom platform, and time-lapse and stereo photographic techniques could be used to document precisely millimeter scale changes in geometry, position or orientation.

Larger scale bed forms, although beyond the observational scope of the bottom platform, are still of importance to this experiment. Many classes of bed forms observed on the deep sea floor (e.g., mud waves, furrows) have length scales larger than the observational scale that bottom mounted instruments can easily observe. Also, it is doubtful that these features migrate or change significantly over six-month time scales, and even the nature of the causal events is not clear. Because large scale bed forms do affect the flow in the near bottom region (even though they may be passive features during the six-month experiment), their existence and distribution should be known and used in the decisions regarding instrument deployment and for data interpretation. However the thrust of the bed form monitoring effort should be aimed at the small scale features.

5. Photographic Scales and Other Imaging Scales

Small scale bottom features such as current ripples are likely to be dynamically active in a high energy benthic region. Indeed, it is the strong flow-sediment interaction in such areas that makes them especially interesting to us. Bed form changes with time must be recorded if they are to be related to the flow. The simplest way of doing this is with a camera photographing the bottom at regular intervals (e.g., once an hour). Depending on the turbidity of the water we could expect to be able to observe an area of the sea bed in the range of 1-100 m^2. While the larger scale coverage would enable us to resolve larger features, this is at the expense of resolution of the small scale features and contrast degradation by turbidity. Moreover, significant movement is less likely for the large scale features than for the small scale features. Hence, the principal camera system should be situated a meter or two above bottom looking at a 1-2 m^2 area of the sea bed. This would be a satisfactory arrangement for recording the behavior of current ripples whose wavelength is a fraction of a meter.

On our stationary rig we should put two such cameras for stereo resolution of the vertical bed form scale. No information is lost if we record the images permanently only when they show change. To do this, the cameras should be miniature solid-state TV cameras with image processing electronics to detect changes. Bed form image

changes might be a good trigger for rapid sampling of the flow parameters. In addition it is relatively inexpensive to put a stereo photographic camera system programmed to shoot once every six hours. This provides a high resolution hard copy output for photogrammetry.

On the "cyclosonde" a camera triggered to take photos at appropriate times could provide "zoom" sequences of variable bottom coverage.

Bed forms large enough to be resolved with a side-scan sonar recorder probably will not show appreciable change during the six-month duration of the experiment, and hence this device is probably not useful in such an experiment.

6. Benthic Mixed Layers

In recent years, layers at the bottom of the ocean have been increasingly encountered in which several properties are distributed more or less homogeneously with height above the bottom. These layers range in thickness from tens to, in places of strong bottom current velocity, hundreds of meters. The present generation of CTD's sees them as absolutely constant in potential temperature and salinity. Concentrations of suspended particulate matter and excess radon, two properties of the near bottom water column with source functions at the sediment-water interface, are also more homogeneous with height above bottom than in areas not displaying the isothermal mixed layer characteristic. These two bottom-source properties however are not completely vertically homogeneous, and profiles through these layers display maxima and minima within, but a sharp decrease in concentrations at the top of the isothermal layers. Given that the lambdas (decay constants) of both radon and coarse particulate matter are much shorter than that of the conservative properties, salinity and potential temperature, it is clear that there are mixing events taking place within the isothermal layer which have a time scale on the order of days to weeks.

Clearly this zone of well-mixed properties has a message for us about how large-scale oceanic circulation interacts with the ocean bottom and how processes which control these well-mixed water-column characteristics affect the erosion, transport and deposition of deep-sea sediments. Simultaneous measurement of temperature, suspended material concentration and settling velocity, and radon at several sites and occasions during the six-month experiment is therefore highly desirable.

7. Entrainment at Top of Mixed Layer

The benthic boundary layer grows thicker by entrainment of fluid from the layer above into the mixed layer. Even if there is little or no mean shear between the mixed layer and that above, internal waves

can produce shear at the density interface that exists at the top of the mixed layer. Shear instabilities move low density fluid downward against the gravitational potential and generate turbulence to mix the fluid into the layer beneath. This entrainment process is difficult to observe with point measurements. The treatment of the entrainment by turbulence at an interface in terms of estimated turbulence velocity and length scales at the interface (c.f. *Turner*, 1973, chap. 9) is attractive. The idea is particularly attractive if a strong feedback mechanism exists between the entrainment mechanism and the generation mechanism for the turbulence. It is useful therefore to explore the possibility of characterizing the turbulence in the well-mixed region of the bottom boundary layer and testing the feasibility of establishing either an entrainment velocity that is small but finite, or even a hard entrainment limit based on the turbulence reaching the interface.

The measurement of entrainment may require flow visualization techniques similar to those used in shallow water at the thermocline that would utilize submersibles or unmanned free vehicles. However, such an experiment is yet to be conceptualized and cannot be addressed by the instrumentation used for the rest of the experiment.

8. Nephelometry

The optical characteristics of a collection of particles depend on the size distribution, index of refraction distribution and shape distribution of the suspended particles. Any one single optical measurement is biased towards parts of these distributions. How then does one choose an optical device? First of all, if the characteristics of a collection of particles are constant, the only variable being the concentration of the particles, any optical measurement will be proportional to the concentration of particulates, if the water contribution is subtracted. Secondly, the theoretical aspects of light scattering and transmission are reasonably well in hand via Mie theory, so that one can design an optical device that is biased towards the desired particle parameters.

The six-month experiment has a requirement for three particle parameters. These are: total particle concentration for the determination of suspended sediment fluxes; determination of the concentration of the large particles in the immediate vicinity of the bottom; and the determination of the small particle concentration with a view toward using them as water tracers. The total particle concentration can be measured by any device, as mentioned above, however, one should maintain contact with theory. A well-defined optical property should thus be measured. A further restriction is the requirement of low power consumption. This points towards the use of photodiodes, rather than PM tubes, and LED's rather than lightbulbs. Large particles scatter most in the near-forward direction (0–1°). A measurement in this region would be heavily biased towards larger particles. Scattering

intensity in this region is also larger than at any other angle, so that power requirements are less. To obtain a meaningful optical signal from large particles requires, unfortunately, a large volume, as their concentration is small. This must be reconciled with the need to measure close to the bottom. Measurement of the small size fraction can be done by either large (>45°) angle scattering, or by using a small volume, and ignoring the spikes due to larger particles. The latter method is more compatible with low power consumption requirements.

A device that could be used for the first two requirements, total particle concentration and large particle concentration, is a large volume beam transmissometer with LED light source and photo diode detector. A small angle measurement (~1°) could be made by means of an off-axis measurement in the same device. No such combination device now exists, although LED-type transmissometers (650 nm) have been used for some time and are able to resolve particle concentration to less than 10 μg/l. The combination device would be used on the cyclosonde.

The small particle device could be a small volume LED-type transmissometer which records the minimum measurement over a time interval of order 1 second. The time period should be long enough to permit undesirably large particles to fall through the beam.

The bottom mounted array of instruments would have both a combination and a small particle optical sensor with event-triggering and routine sampling capabilities. In this way both the background and the occurrence of resuspension events would be monitored. Ideally more than one large-particle sensor would be deployed in order to determine concentration gradient of large particles. Some measure of particle settling velocity distribution (preferable) or size distribution (acceptable) would be very valuable. Existing optical counters might be adapted for the purpose, though this is not a first priority item for the bottom array.

9. Sediment Flux

In studying the process of sediment transport in the benthic boundary layer it is important to determine the flux of material vertically transported both into and out of the boundary layer, as well as horizontally advected in the boundary layer. Measurements of these fluxes temporally and spatially are necessary to answer the questions

(1) Is the area being studied undergoing deposition or erosion?

(2) What is the periodicity of important material transport events?

(3) What are the residence times and distances of transport of suspended sediment?

To determine these fluxes a combination of current measurements suspended material measurements (optically with calibration through filtration) and sediment trap flux determination are necessary. Sediment traps, designed to catch the material which is in vertical flux through the water column, are used to measure the flux of material into the boundary layer. Downward flux can also be determined by measuring concentration of suspended material and its settling velocity, if there is no upwelling, i.e. $w = 0$. Horizontal fluxes within the boundary layer are measured by combining current velocities with concentrations of suspended material. Sediment traps, now being designed to collect the horizontal flux, will be useful for obtaining samples of the transported material.

Sediment traps for vertical flux are now being designed with sample changers so that approximately eight samples can be taken during the experiment; i.e. one or two per month. Calibration of the optical sensors in terms of sediment mass concentration needs to have been done before deployment. During monitoring periods the instantaneous product of velocity and concentration would be formed and the contributions of mean and turbulent eddy components determined. Raw data would not be recorded, only derived quantities.

A set of measuring stations needs to be deployed in order to monitor fluxes through an area. The separation of the stations must be such as to ensure a fair degree of coherence between stations. Spacings of one to two km across the flow and up to 10 km parallel with the flow would probably satisfy this criterion.

IV. THEORETICAL AND LABORATORY WORK

A. Numerical Modeling of Benthic Boundary Layer Flow

Modeling is an important facet of any oceanographic project and, in the case at hand, the use of theoretical concepts in a mathematical framework to summarize available understanding and to predict results that can be tested in the field certainly is necessary. The remoteness of the environment, the logistical difficulties of making many critical types of measurements to the required accuracy and the need for guidance when designing sampling programs make such models an essential component of the overall program.

Due to the well defined and basic nature of the physical oceanographic part of the problem and the existence of a suitable set of conservation equations in this area, modeling of near bottom current and density fields is somewhat easier than the modeling of geological and biological phenomena; thus, this comprises the appropriate area in which to start such an effort. *Weatherly and Martin* (1978) and others already have addressed this problem to some degree, the former authors use the higher closure scheme of *Mellor and Yamada* (1974) as the basis for their calculations and find that the resulting model is in reasonable agreement with available experimental results. For use in the benthic boundary layer project of concern in this document, this numerical model, or a similar one, needs to be generalized to include spatial gradients imposed by sloping isopycnal surfaces and non-planar bottom topography, as well as any density field disturbances that may occur under high velocity events, due to the presence of dense clouds of resuspended sediment. Other closure models also are available, but theories for flow in the benthic boundary layer based on them suffer from the same deficiencies.

Once a comprehensive model for the Ekman dynamics of the near bed region is available it can be adapted to include the effects of small wavelength bottom topography and sediment transport in a parametric sense, much as suggested by *Smith and McLean* (1977 a,b). Further, this can be used in conjunction with the best available sediment transport information to permit calculation of vertical and horizontal sediment fluxes. As new information of a geological or physical oceanographic character is gained from field studies, the basic fluid mechanical model and its sub-components should be updated. The model must be thought of as an evolving entity, not a static one; one that always represents the best quantitative summary of available information on the topics that it addresses.

B. Laboratory Work on Turbulence in Flow Over a Rough Bed

A series of measurements over rough beds is envisaged to examine energy production and dissipation with a view to parameterizing the high frequency in terms of easily measured mean values. Results from the laboratory would include Reynolds stress cospectra, dissipation and production terms, probabilistic structure and spatial structure.

1. Fixed Bed

Measurements can be made over artificial beds with easily parameterized roughness and over replicas of natural beds made either from box cores or from photogrammetric contour diagrams. In the latter case aspects of the turbulence structure can be investigated over "natural" beds under controlled conditions. This should provide valuable input to interpretation of turbulence records from the three-day experiment. Phenomena to be examined include:

(a) Generation of "bursts" and their characterization in transition and rough bed flows (no data for boundary layers that are fully developed exists except *Grass* (1971).

(b) The effect of microtopography and roughness spacing on boundary layer structure, including characterization of roughness.

2. Mobile Bed

We have no data at present on turbulence characteristics in boundary layers under conditions of transport. Similarly, we have no data on the relative contribution of form drag and skin friction. Techniques of fixing an equilibrium bed and evaluating stress profiles would yield skin friction plus form drag; painting the bed waves to get them locally, hydraulically smooth would yield results on form drag alone. This work would give some dynamical scaling parameters for input to a boundary layer model.

Instruments would include hot films, both conical quartz coated and custom design platinum films (the only available sensors with known adequate frequency response), hydrogen bubble techniques and possibly for fixed bed work a 3-D laser Doppler anemometer. Gust has experiments underway to measure turbulence fine structure in clear and cohesive sediment-laden sea water flows over smooth and rough beds. Other work is vital given the large controversy on boundary layer structures even with smooth walls (*Kline, et.al.*, 1967; *Kim, et.al.*, 1971; *Brodkey, et.al.*, 1974; *Willmarth*, 1975; *Falco*, 1977), using different instrumental techniques to obtain structural measures of transition and rough wall flow characteristics.

C. Flume Experiments on Cohesive Material

With few exceptions (*Krone*, 1962; *Partheniades*, 1965; *Owen*, 1975) the conditions for entrainment of cohesive sediment have not been studied either in the laboratory or the field. The present approach to the entrainment process is to use the results of laboratory experiments in which threshold data were collected under very special (and simple) conditions, i.e., steady, uniform flows over flat, non-cohesive sand beds of uniform grain size. Flume experiments should be directed at eliminating the limitations of these previous studies.

The first problem is to define a set of physical criteria by which to characterize the natural sediment. The traditional measures such as grain size and mineralogy should be retained, but these must be supplemented by geotechnical properties such as:

(a) Shear strength (vane shear)

(b) Index properties; i.e. Atterberg limits, cation exchange capacity

(c) Physical properties; i.e. water content, porosity, density

(d) Sediment microstructure (fabric) using SEM, TEM, etc.

(e) Non-destructive measurements: compressional and shear wave velocity, reflectivity, gamma-ray attenuation, ultrasound

(f) Shear stress and pore water pressure (within sediment layer)

(g) Other measures that relate to the binding of sediment by biological activity.

Once the bed is characterized, flume experiments should be directed at determining the conditions of entrainment, first over a flat bed and then over a surface containing roughnesses of various characteristics. A criterion for entrainment needs to be defined and related to parameters of the turbulent flow. Not only the critical condition but also the erosion rate constants for different mud beds need to be determined. The conditions under which sediment is redeposited must also be determined, in particular the shear stress and settling velocity dependence of deposition rate.

The details of the flow in the boundary layer are modified by the presence of material in suspension. At present we have little data on the nature of this modification (*Gust*, 1976; *Vanoni*, 1975). A series of experiments needs to be directed at determining the velocity structure of the boundary layer at hypercritical and non-depositional shear stress while the flow carries material in suspension.

D. Laboratory Measurements in Relation to Biological Systems

1. Undisturbed Box-Core Materials In Flumes

Undisturbed sections of the deep sea sediment will be placed in a flume with as little disturbance as possible and subjected to a series of flow experiments as set out in the preceeding section.

2. Biological Work

These studies are designed to assess the importance of biological sediment binding and sediment reworking to the stability or erodibility of the sediment-water interface. Even though deep sea macrofauna can be recovered and maintained in the laboratory there is serious question as to whether their physiological behavior has been affected. Bacterial populations and densities do appear to be altered once sediments are removed from the deep sea and it is likely that metabolic activity including production and destruction of binding agents are changed. Therefore, at this time, it may be necessary to examine and evaluate binding and sediment reworking in nearshore sediments of similar grain characteristics where we can find organisms, especially macrobenthos, of similar size and functional group to deep sea fauna in the study area.

One major difference between deep sea and nearshore bottoms which may be significant is the variation in organic matter both in quantity and quality. Recent models, for example, suggest that feeding rates of deposit feeders will depend on sediment organic content. This is something which will have to be considered in relating the results of laboratory and shallow water experiments to deep sea processes. In order to determine what reasonable current velocities should be used in flume studies we need basic flow statistics from field measurements.

Manipulation will involve inhibiting reworking activity and mucus or tube (polychaete, amphipod) binding in box cores or natural sediment. The resulting change in τ_c (critical erosion shear stress) will be measured. One way to evaluate the relative importance of binding and sediment reworking is to compare temporal changes to a standard critical erosion measurement on replicate box cores in which all organic activity has been stopped and all surface biogenic features have been eliminated.

V. SURVEYING AND SITE SELECTION

A. Introduction

Prejudices concerning the site selection criteria (SSC) for HEBBLE have developed over the past 15 years in the minds of a small number of investigators who have been studying microphysiography of the abyssal sea floor and trying to relate observed features to hydrographic data and sparse data from current meters placed far from the bottom. It has only been in the last few years that enough data, of the right kind, has been obtained showing that some of the bed features are actually being formed and modified, now, by active processes associated with near bottom ocean circulation.

Although very little is known about both bed forms and low frequency (>2 days) variability in bottom flow, geological studies of sediment dynamics have been based on this morphologic and hydrographic information together with observations of sediment structures textures and grain sizes in cores. Parallel to this effort has been the development of theoretical ideas concerning boundary layer flow, deep mixed layers as seen by nephelometers and the recently developed CTD, and the realization that near-bottom current speeds of ocean flow are often unexpectedly high with strong fluctuations. Taking this into account the majority of participants in the present HEBBLE Workshop accepted the following site selection criteria:

(1) Regional (100's to 1000's of kms^2) description of sea floor

- (a) topographically uncomplicated on a meso-scale (100's to 1000's of meters)
- (b) covered with cohesive (clay to clayey silt) sediment that displays
- (c) well developed current produced bed forms of the scale (λ) of 10's of cms to 10's of meters (i.e. from small crag and tail, through mud ripples possibly to abyssal furrows).

(2) Water column characteristics

- (a) an area of known or suspected high flow speeds, ideally in areas of strong mean flow and weaker low frequency variability; not downstream of large eddy-shedding topographic elements
- (b) modern continental input of terrigenous debris should be as low as possible (ideally zero)
- (c) a region of characteristic water-mass parameters that can be identified and traced.

A more formal way of guiding the selection of a site is through use of the conservation equation (e.g. for suspended sediment) to provide a framework:

$$\frac{DC}{DT} + \lambda C + \bar{\nabla}\cdot\bar{F} = 0$$

C is the concentration
λ is the settling rate, a function of particle size
$\bar{F}$ is the flux of C, often parameterized in the water column as
$\bar{F} = -D\nabla C$ where D = dispersion coefficient
and D/DT = total derivative = $\partial/\partial t + \vec{u}\cdot\nabla$

Within this framework we are searching for a region at which the substantive derivative DC/Dt can be approximated by $DC/Dt \approx u\cdot\nabla c$. In other words, the importance of temporal variability is small relative to other aspects. This is a site selection criterion for the large scale and should not be taken to imply that temporal variability is considered unimportant, particularly at smaller scales.

We are also searching for sites at which either none or hopefully only one of the remaining terms is varying. As a group, two possible sites are favored, the Blake-Bahama Outer Ridge and Scotian Rise. More preliminary survey work is required before a definitive site can be proposed.

The methods of identifying and surveying such areas will vary considerably depending on the scale and location being examined. However they can be broken down conveniently into the following three phases:

Phase 1 The collection and synthesis of all presently available data, identifying areas warranting further study.

Phase 2 Field operations in these areas using rapid surface vessel survey techniques (e.g. 12 and 3.5 kHz) with limited station time for CTD, bottom camera and nephelometry.

Phase 3 Detailed near-bottom microphysiographic studies using deeply-towed echosounder, side scan sonar and stereo cameras with ancillary moored short term current meters. Determination of site variables such as bed shear strength and erodibility would be carried out using an instrumented sea bed flume. Box cores of the bed would be obtained for laboratory determinations as set out in Sections III B and IV B, C, and D. Subsequently there would be two experimental programs:

Program 1: deployment of near bottom, short term (e.g. 3-day) experiments including time-lapse cameras, Reynolds stress sensors, stacked current meter arrays, recording transmissometers (short HEBBLEs).

Program 2: deployment of long term (6 month) HEBBLE with cyclosonde and full scale bottom monitoring array with microprocessor control.

We think it feasible to do it in the following time sequence:

1978: Do Phase 1 (a continuing activity) and some areas of Phase 2.

1979: Do Phase 2 and a deep-tow survey (part of 3) followed by a basic short experiment of Program 1.

1980/81: Concentrate on surveying (phase 3) and 3-day HEBBLEs of Program 1 while designing the equipment for the experimental Program 2, i.e. 6 month HEBBLE.

1982: Begin shallow water field tests of 6 month HEBBLE equipment while continuing use of 3-day HEBBLEs.

Post-1982: Conduct 6 month HEBBLEs.

B. Survey Procedures for Site Suitability Determinations

Phase 1: Global Syntheses of Available Data

This effort, which is by its nature ongoing, provides the basic level of site identification. It is at this stage that whole ocean basins (western boundary current systems) are quickly narrowed to smaller scale study sites thought to fit the site selection criteria (SSC). This task should be delegated to an appropriate group of investigators forthwith. An open discussion of this phase of the HEBBLE project should constitute the agenda for the next HEBBLE Workshop possibly in the Fall of 1978, after the ENDEAVOR cruise and MELVILLE deep-tow cruise of Summer 1978.

Phase 2: Large Scale Site Survey Operations

This effort would, for this project, commence in the 1979 field season on research vessels operating as near as possible to the Western Boundary Undercurrent (WBUC) on the North American continental rise, the first targets of the HEBBLE program. Phase 1 will broadly outline areas of 2-5° on a side within which more detailed work is required. Well equipped oceanographic research vessels should be employed for this phase and should have the following equipment for surveying:

(1) high frequency echo sounding (12 kHz)

(2) mid-frequency, high resolution sub-bottom profiler, 3.5 kHz

(3) Loran C and satellite navigation

(4) hydrographic winch with conducting cable for CTD, nephelometer/transmissometer, bottom bounce camera with pinger and

(5) hard-wire (1/2 to 5/8") winch for box cores and survey cameras (e.g. ANGUS).

The survey team will utilize the above systems as required for the purpose of identifying sub-sets of areas (10's to 100's of km^2) for near bottom detailed surveys of Phase 3.

Phase 3a: Near-Bottom Underway Surveys of Microphysiography

Prior to deployment of any bottom-mounted instrument and well before we deploy three-day HEBBLEs a detailed (i.e. overlapping side-scan sonar coverage) survey of a region (e.g. 100 km^2) should be done using the MPL deep-tow system.

Since the smaller features (e.g. furrows) can be resolved only by near-bottom side-scan sonar, the use of the deep-tow vehicle will be required to locate the sites for the next phase. The vehicle's side-scan sonars (SSS) and bottom cameras would determine the type of bedforms in the area and their variation along and across the flow path. Although this coordinated use of SSS and cameras is the most efficient way to define the types of bedforms, it is still a relatively slow process with SSS search rate of about 3 km^2/hr. The best method of site location will probably be by long "unnavigated" (i.e. beyond range of acoustic transponders) tows on sinusoidal tracks along desired stretches of the WBUC. This type of reconnaissance mapping would take from 8-10 days.

If the desired site is to be as homogeneous, flat and smooth as possible with roughness elements of only a few cm in vertical and horizontal scale, the role of a transponder-navigated deep tow (of e.g. a 10 x 10 km area) would be limited to ensuring that there was no excessively complicating roughness. It might be possible to photographically map patterns of fine-scale roughness elements within the area, (e.g. do the crag and tail systematically vary in size?) but the mapping rate is very slow 0.01 km^2/hr, and many of the smaller features are poorly resolved on large-area vertical incidence deep-tow photographs.

If the desired site is to be an area of active erosional furrows, a transponder-navigated survey of a 100 km^2 would determine the characteristic dimensions of the bedforms (depth, width, spacing, length, their lateral continuity and degree of branching and (by photography) the differences in microtopography between furrow floors, sides, and interfurrow areas. High-resolution sub-bottom profiling would determine whether shallow strata are truncated by the furrow walls, an indicator of the recency and extent of erosion.

If the desired site has furrows with spacings of several hundred meters, and there is some expectation that there might be spatial variations at similar scales within the boundary layer, the deep tow system can collect continuous CTD and nephelometer data at any depth from a few meters above the sea floor to the top of the boundary layer. The uncertainty in plan position is 5-10 m, and in depth and altitude about 1 m. The advantages of making these measurements from the deep tow vehicle, rather than by towing a conventional CTD on a standard wire are the greater ease of positioning and precision of navigation and, but more significantly, the spatial patterns perceived by nephelometer and CTD could be related to simultaneously observed patterns of microphysiography. We would also be interested in, for example, whether the CTD shows evidence of secondary helical circulations with a spacing half that of the furrows and whether there are different concentrations or different types of nephels (suspended particles) in furrow and interfurrow strips.

At any high energy site, the deep tow vehicle would be able to spread tracers at any known (and desired) position and altitude. These might be dyes or neutrally buoyant particles that could be traced using sonar in order to characterize flow patterns using suspended particle motion, or marked grains that would be deposited in a veneer on the sea floor, to be subsequently cored for information (for example) on biogenic reworking.

Areas of 100 km^2 are routinely surveyed by positioning the deep tow vehicle with respect to 3 to 6 bottom-moored acoustic transponders. Samples and sensing devices (e.g., current meters) are then positioned with respect to the same beacons, by attaching relay transponders to them. Some of our transponders may be left in place for several years, providing "permanent" benchmarks for the location of any other observations. All measurements within the HEBBLE site(s) should be precisely located, relative to each other and to the topography, in this manner.

In summary, presently operational deep tow systems that may be useful in the HEBBLE are:

(1) high resolution bathymetric profiling

(2) 120 kHz side-scan sonars

(3) 4-6 kHz sub-bottom profiles

(4) snapshot TV and stereo black and white and color bottom photographs

(5) Savonius current meter rotor

(6) a thermometer

Additional instruments that have been successfully used on the vehicle in the past 2-3 years and which could be added for HEBBLE work are:

(1) a filtering pump for obtaining suspended sediment (opened and closed on electronic command)

(2) a nephelometer

(3) a Neil Brown CTD

(4) electronically closed water sampling bottles

(5) an electronically controlled plankton net for sampling near-bottom fauna

(6) a sand spreader, for injecting marked sediment onto the bed.

Phase 3b: Box Coring of Deployment Area.

Prior to deployment of the first experimental phase, i.e. a short HEBBLE, a network of bottom-navigated box-core samples should be taken for laboratory work on grain-size, mineralogy, geotechnical properties, biota and its effects on the uppermost layers of the sea floor.

The following questions will need to be addressed in this phase:

What variation in depositional processes/rates do we find with core depth, i.e. is the present regime representative of the recent past (Holocene)?

In order to test for possible horizontal and vertical variations, we must develop sampling technique patterns that allow us to obtain maximum information from the minimum number of samples. Samples should be obtained in box cores of 20-70 cm^2 and (if possible) 50 cm in depth to allow us to completely sample the Holocene section. Such samples will also be used by biologists for faunal studies, for flume studies on the critical erosion stresses and erosion rate constants, and, using surface replicas, on the effects of roughness on flow characteristics.

Technology presently exists to obtain such samples. However, to prevent loss or disturbance of the upper few mm of material (i.e. that of particular interest in terms of bottom animal/sediment interaction and erosive character) we must make sure the material does not slop around once sampled. Such loss or disturbance could occur on impact of the sampler, during pull-out from the bottom, upon transit through the water column (less likely), or on bringing the sample onboard the ship. Perhaps the upper few mm in selected samples are best preserved by <u>in-situ</u> freezing, possibly by injection of liquid nitrogen/helium or a polyester resin. The careful preservation of grain-to-grain relationship would allow SEM studies of sediment fabric in the upper few mm and flume erosion studies of the undisturbed interface.

The box cores obtained should be analyzed for accumulation rates and primary structures to determine lateral variations in erosional/depositional patterns. Foraminifera/nannoplankton can be used to define Quaternary stratigraphy and the thickness of Holocene material. Box-core sampling should be guided by attitudes of near-surface sub-bottom reflectors observed in high frequency (12 kHz) reflection records, and the rates/structures should be correlated with these records.

The second problem to be addressed is the strategy used in selecting sites for cores: how many and where?

Obviously, the number of cores depends directly upon the sedimentological/morphological variations noted in the area. Presumably fewer samples are needed to identify sedimentological variations in an area with homogeneous morphology. However this does not preclude the problem of identifying the areal distribution of sedimentological properties themselves. In other words, if a 1 km^2 area is completely homogeneous with respect to surficial sediments then 10 box cores would be too many. On the other hand, if sedimentological variations are great, 10 may be too few. The answer to this possible dilemma may be found by remote sensing of the sediment character. For example, high frequency echo sounding from a deeply towed fish could delineate the structure of the upper 10's of meters. In fact recent data show that convolving the outgoing 4 kHz pulse from deep-tow with the reflection coefficient log generates a synthetic seismogram that very closely resembles the 4 kHz reflection profile. Thus it may be possible to remotely determine the physical properties of the sediment column.

Side-scan sonar can delineate variations in surface features as well as gross changes in sediment texture (reflected in the strength of the echo return). These data can be supplemented by oblique bottom photography. Very high frequency profiling (2-5 MHz) may allow delineation of finer scale textures on the cm to mm scale within the upper few cm of the sediment column. Using these tools may aid considerably in defining a sampling strategy. If neither remote sensing nor bottom morphology aid in constructing a sampling pattern, we may be forced to sample on a geometric grid.

Phase 4: Deployment of Three Day HEBBLE

The above suite of observations will have been completed so that the major decisions concerning the actual deployment will probably revolve around the actual placing of this experiment vis-a-vis the bedforms. That is, where and how should a single (or a multiple) array be placed, and how can we know whether it has been placed properly?

Under our working assumption that we'll get smarter about such things as this program progresses, we will probably attempt our first launch in a region so uniform, with respect to bedforms, that it won't matter within a km^2 where it actually is placed. During the time frame of the experiment (~3 days), the surface ship will continue to survey so that the immediate area is particularly well known. The bottom structure will carry a camera above it to give a photograph of the experiment sitting on the sea floor. At the conclusion of the experiment, we would decide whether more arrays (or single sets) of the three-day experiment should be deployed in a subsequent year while we begin to tune up for the six month HEBBLE.

Phase 5: Six-Month HEBBLE

As is outlined above this experiment(s) would comprise a very complex set of bottom and near-bottom sensors. It will require a detailed engineering feasibility study with a significant commitment of funds and time before an actual deep ocean deployment is attempted. This approach follows the agreed timing of the six month experiment and it is anticipated that the HEBBLE program will evolve in the early 1980's but probably not before we have analyzed data from three day experiment(s). (see Management chapter)

It is conceivable that the following phase of the HEBBLE program will consist of arrays of six month experiments on large sets of active bedforms, e.g. mud waves, but planning for this will have to evolve as the program begins to run and serious commitments are made by principal investigators and funding agencies.

VI. ENGINEERING REQUIREMENTS

The Engineering Group considered two types of engineering problems of HEBBLE. Specific developments of technology (at least for oceanography) and routine engineering specifications were considered first. It was anticipated that only a limited number of instrument developments would be tolerated since the integration of many established measurement programs would be, in itself, a large undertaking.

The topics of specific engineering details were:

A. Data Processing Implementation

B. Image Analysis and Processing

C. Power Requirements and Supplies,

D. Structures and Emplacement

E. Experiment Servicing

F. Pretesting

A. Data Processing Implementation

High frequency sensors will generate too much data to be continuously sampled. Thus, processed data or conditionally sampled bursts of high frequency data must be stored from these sensors instread of raw data. This requires in-situ data processing. Individual measurement programs can preprocess data with microprocessors to compress the raw data into a smaller set of derived quantities. In general, however, interaction between instruments may be necessary to derive covariance or other measures of interest. This requires central in-situ processing in addition to individual processing. Compatible formats and control protocol should be established as for example the IEEE 488 general purpose interface bus standard. This will retain flexibility of interaction between measurement programs. At a minimum, time will be available on this bus. Further, standards of program control will need to be decided upon when the specifications for the measurements are established.

Preprocessed data must be carefully and periodically validated since the bias of processing can intrude in subtle ways on the output. This requirement can be partly met in pretesting of individual measurement programs and in pretesting of the integrated experiment. However, in-situ validation is also required. This will be possible through the burst sampling mode which is event-triggered. In this mode, raw data will be recorded for a certain period--10 minutes for example.

The trigger for burst sampling will be derived from a number of measurements, possibly in combination. This in turn requires central in-situ processing. The event trigger program can poll the appropriate sensors through the bus and determine whether burst sampling is justified or not. When a burst is justified, it will trigger the raw data recording for the burst period.

B. Image Analysis and Processing

1. Six-Month Experiment

Images from TV cameras mounted on the HEBBLE structure are a proposed means of triggering data-taking activities. The loss of image detail caused by an increased nephel influx or motion of any bedform resolved by the image is the anticipated condition that will enable the triggering. Detection of any change in image quality could be accomplished by a two-dimensional Fourier analysis; a reduction in the high spatial frequencies would then activate the other devices. Only a subset of the TV image needs to be retained for further analysis in order to minimize storage requirements.

In order to monitor the movement of any bottom features present at the HEBBLE site, a technique of change detection using image differencing can be used. Images taken at time intervals appropriate to the motion can be subtracted from one another, assuming frame to frame registration is maintained, to show only those objects that changed position. The resulting difference picture may be retained or also used only to trigger a data collection sequence.

Efforts to interpret the images may benefit from computer image restoration and enhancement techniques.
Contrast enhancement improves visualization of details, spatial filtering often serves to suppress shading gradients or to selectively emphasize scene features and geometric rectification provides the ability to alter the perspective. These and other techniques are best invoked after the data collection phase of the experiment.

For some users of the stored TV images the resolution may not be sufficient for their work. Photographic cameras would overcome this to a degree and should be included in the experiment.

C. Power Requirements

The proposed experiment consists of many subsystems which have differing power requirements. The low power systems such as current meters and thermistor chains will provide their own power from batteries housed in their respective instrument cases. The subsystems which require large amounts of power will be connected to a bank of lead-acid batteries which could possibly serve as part of the anchoring system. The three main users tapping into this supply are the Profiler Winching System, the Television System, and the strobe lights for the time lapse photographs. The current drains from each will be centrally monitored to assure that a malfunction of a subsystem will not jeopardize the availability of power to the other users. The power for the Profiler Winching System will be completely isolated so as to avoid large voltage transients in the other systems.

For an experiment lasting six months, this bank of batteries will be in pressure compensated packages approximately 1 meter on a side, and this represents a source of flow disturbance which must be recognized both during deployment and in the data analysis. Cables from the batteries to the subsystems will be buoyed off the bottom to avoid introducing artificial roughness elements.

D. Structures and Emplacement

The Engineering group has identified two basic structural types for a benthic boundary layer experiment. First, is a profiling instrument designed to measure three axis current, temperature,

conductivity, nephels and take photographs. This structure is envisioned as a winch system either pulled up and down a taut carrier cable, or a buoyant housing allowed to rise and then winched down. The structure would be similar in either case with bottom mounted winch and power supply and possibly bottom mounted data processing and recording to minimize the size of the actual profiler. The second structure is a large tripod of approximately three meters on a side. The legs would be vertical to cause a minimum of disturbance to the flow throughout the several meters nearest the bottom. This structure provides ample sites to install instrumentation such as video systems, photography, as well as velocity, temperature, conductivity and nephelometry at fixed heights above the bottom.

The emplacement of the structures used on the experiments should be lowered in an acoustic net established during site survey. This will ensure emplacement in an area of known bedform. Both generic types of structures discussed are complex enough that a lowering line will be required to ensure a soft landing and improve reliability. The use of a lowering line will also make it possible to orient the tripod if conditions are known sufficiently well to make this desirable.

E. Servicing the Experiment

The Engineering group examined many of the factors involved in servicing the experiment. There is a complex set of trade-offs that must be made in a continuous fashion as experimental design progresses including data capacity, system design, power supplies, site selection and cost of ship-time. Clearly the cost of ship-time indicates that great care must be taken during design so that the frequency of servicing is not excessive. Six months is seen as a reasonable goal. For a continuing experiment the transponder net should remain active throughout the duration of the experiment to allow replacing the instrumentation in the same immediate area. Engineering design of sensors and systems should be such that all servicing, except catastrophic failures, can be done on board the recovery ship. Instrument design should include a rapid, simple checkout procedure that can be performed on board. The recovered instrument should be capable of having its power supply, tape/film replaced and checked out quickly enough to make servicing a serial procedure. That is to say, the ship will recover one system, service it quickly and re-emplace it before going to the next system. This will allow the use of a smaller and therefore less costly ship for servicing than is required to transport and emplace the entire experiment initially.

F. Pretesting

Before attempting the full-scale deep-sea deployment, all of the subsystems will have to be tested both individually and as components of an integrated experiment.

The pretesting program can be divided into three major elements. These are:

1. The Profiler Winch System will be deployed in relatively shallow water to determine its operating characteristics and power consumption.

2. Various preprocessing and conditional sampling schemes will be tested in shallow water, in experiments of short duration (on the order of days) in order to see how these two elements affect the final results.

3. Once all of the subsystems appear to be working and compatible with each other in the laboratory, a three day experiment in deep water will be performed which in part will be an engineering test of the integration of all the components of the system.

The results from the three day experiment will also be important in terms of setting the thresholds for preprocessing and event triggering at the actual site of the six month experiment. This information could not be obtained from the shallow water tests.

VII. MANAGEMENT

As is the case in all complex and multidisciplinary field efforts the ultimate success depends largely on sound scientific thinking coupled to adequate management structure. The high degree of interaction between measurement programs and the common use of experimental structures, deployment, and servicing of the experiments requires a high degree of coordination. Two routes toward this task were considered: contracting the entire experiment to a single agency, e.g. Jet Propulsion Lab, or retaining individual control by forming a central Executive Committee reporting to a Project Director. The outside agency approach would be costly but certain agencies are experienced in handling this scale of experiment. The advantages from a scientific point of view are that a single body would be responsible for meeting engineering specifications and schedules. However, it would be unlikely to be chosen by the individual investigators and thus would be more likely to be imposed by an executive committee if in fact the choice were made to go to an outside agency.

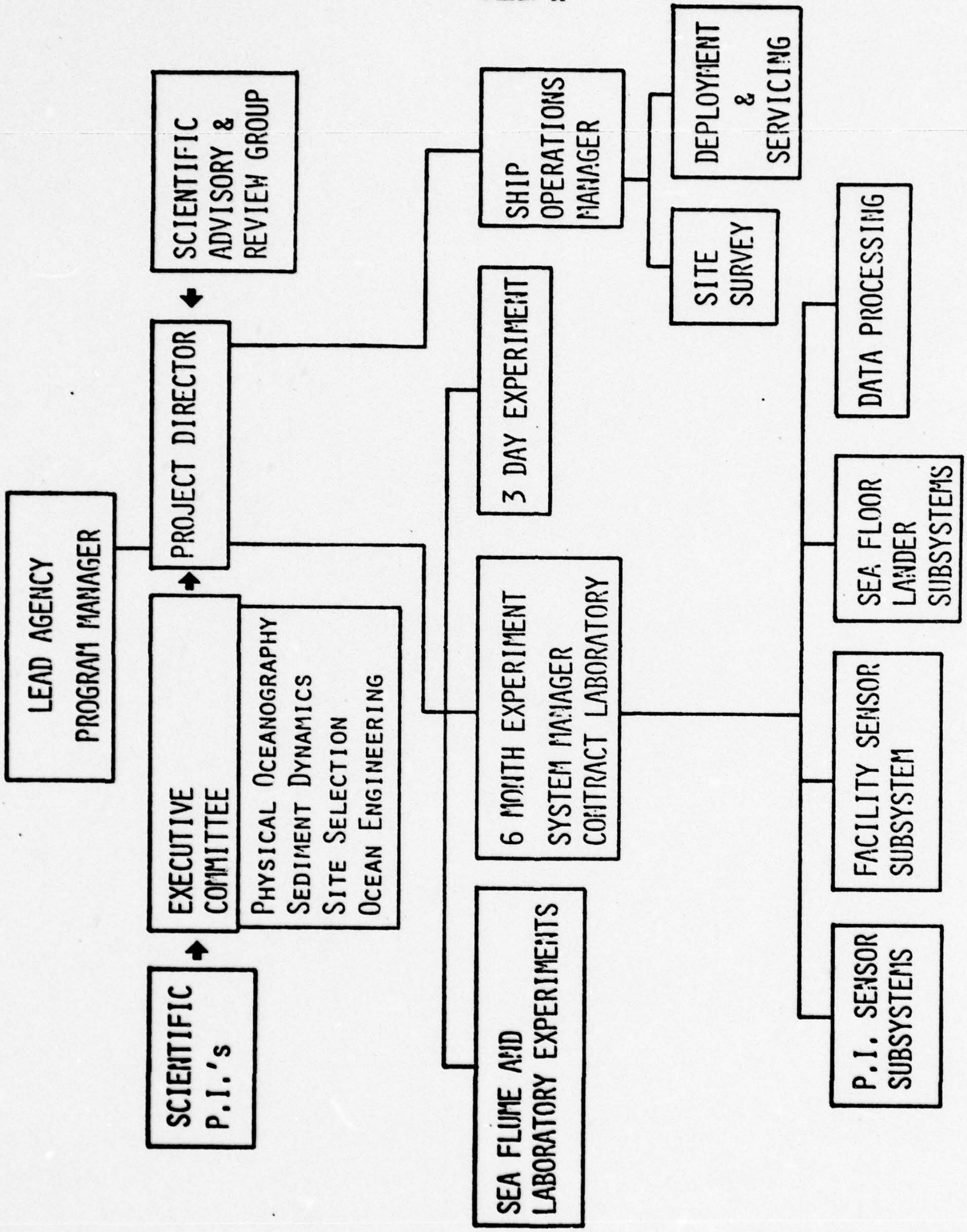
Because outside contracting agencies need to deal with a positive and direct line of responsibility, a Project Manager with executive responsibility is necessary. He would also be ex-officio chairman of the Executive Committee. The site selection deployment and servicing decisions would be decided by the Project Director with direct input from the Executive Committee. Ultimately, the inclusion of individual measurement programs on the central experimental structures would have to be decided by the Project Director. Peripheral or weakly interacting experiments should be reviewed by the committee which might recommend the addition of the measurement to the overall experiment but would not control inclusion of the program.

Standing subcommittees would be needed to address the problems of post-experiment data processing and distribution and pre-experiment testing and validation. Other subcommittees would concern themselves with <u>in-situ</u> processing, power consumption, mechanical compatibility, and electrical compatibility.

A <u>trial</u> table of organization, based largely on response to a letter requesting declaration of intent from all of the Workshop participants follows. This is seen as a possible structure balancing the essential scientific components of an experiment with the necessary engineering and management functions.

Most of the groups in this table have obvious responsibilities. The Executive Committee would have lead principal investigators from the fields of physical oceanography, sediment dynamics, ocean engineering and sea bed surveying.

PLAN A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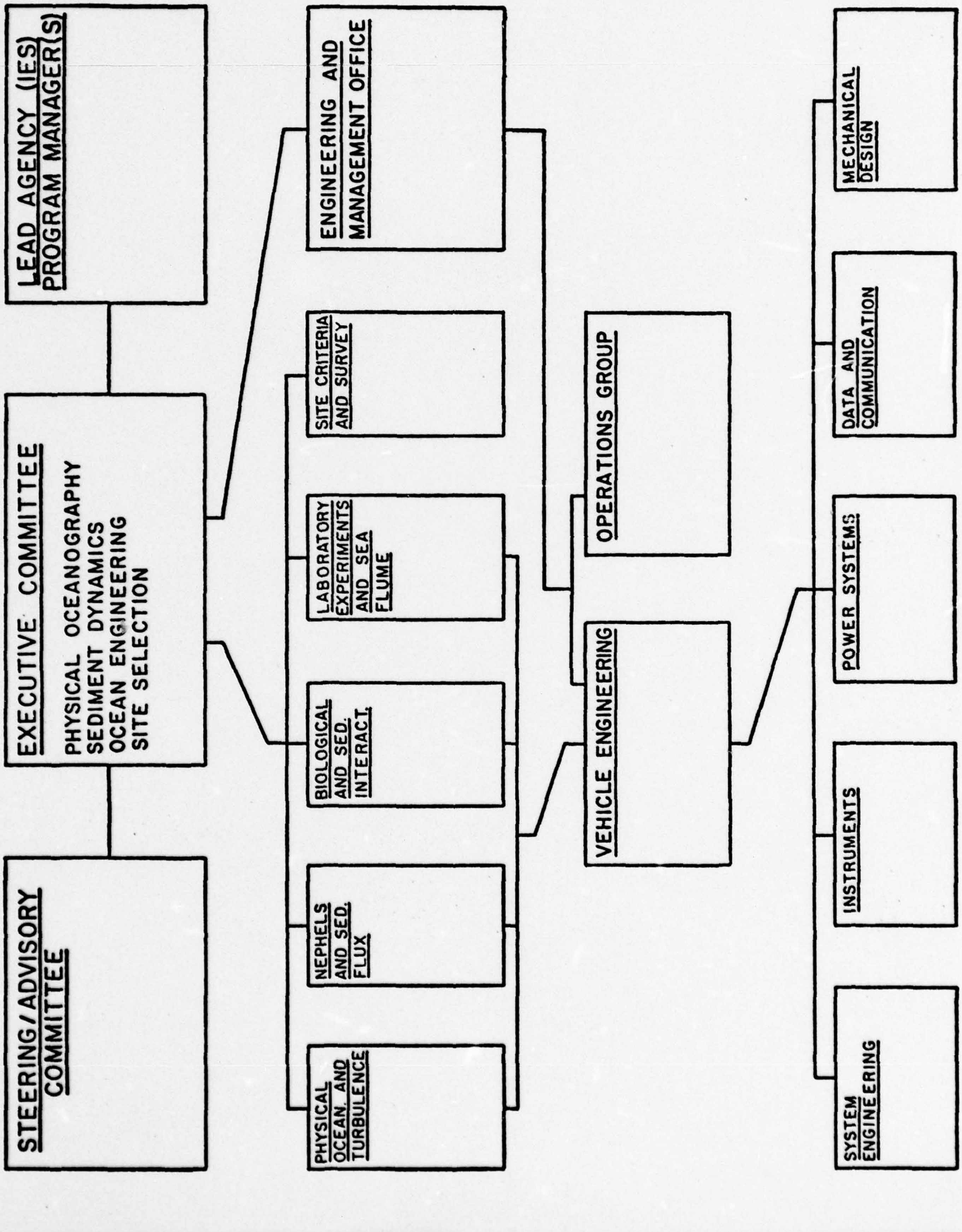
SCIENTIFIC P.I.'s
EXECUTIVE COMMITTEE
PHYSICAL OCEANOGRAPHY
SEDIMENT DYNAMICS
SITE SELECTION
OCEAN ENGINEERING
PROJECT DIRECTOR
SCIENTIFIC ADVISORY & REVIEW GROUP
SEA FLUME AND LABORATORY EXPERIMENTS
6 MONTH EXPERIMENT SYSTEM MANAGER CONTRACT LABORATORY
3 DAY EXPERIMENT
SHIP OPERATIONS MANAGER
SITE SURVEY
DEPLOYMENT & SERVICING
P.I. SENSOR SUBSYSTEMS
FACILITY SENSOR SUBSYSTEM
SEA FLOOR LANDER SUBSYSTEMS
DATA PROCESSING

PLAN B


LEAD AGENCY (IES)
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EXECUTIVE COMMITTEE
PHYSICAL OCEANOGRAPHY
SEDIMENT DYNAMICS
OCEAN ENGINEERING
SITE SELECTION
STEERING/ADVISORY COMMITTEE
ENGINEERING AND MANAGEMENT OFFICE
SITE CRITERIA AND SURVEY
LABORATORY EXPERIMENTS AND SEA FLUME
BIOLOGICAL AND SED. INTERACT.
NEPHELS AND SED. FLUX
PHYSICAL OCEAN. AND TURBULENCE
OPERATIONS GROUP
VEHICLE ENGINEERING
MECHANICAL DESIGN
DATA AND COMMUNICATION
POWER SYSTEMS
INSTRUMENTS
SYSTEM ENGINEERING

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APPENDIX I. CURRENTS AND TURBULENCE

Chairman: M. Wimbush

Rapporteur: J. D. Smith

Participants: G. Weatherly
L. Armi
A. Nowell
G. Gust

A. Introduction

In this group the physical oceanography of the benthic boundary layer was examined. It seemed most efficient to get the individuals with expertise in different parts of the frequency spectrum to set out their opinions on what is necessary. This report therefore starts with high-frequency turbulence and proceeds to longer period motions.

B. Turbulence Structure in Wall Bounded Shear Flows

1. Facts Presently Known

a. From laboratory flume research

The energy density spectrum of Reynolds numbers Re = $\frac{U_\infty \delta}{\nu} \sim 10^4$ (U_∞ free stream water velocity, δ boundary layer thickness, ν kinematic viscosity) ranges up to ~100 Hz. The highest expected (but probably insignificant) turbulent fluctuation in oceanic current systems (U_∞ several knots) are 1000 Hz. The turbulence field is non-Gaussian. The vertical distribution of moments from order 1 to 4 (mean values to flatness) is known in the (logarithmic) boundary layer. The Reynolds stress and turbulence production is intermittent and occurs in "bursting".

Measured parameters of the ejection-sweep cycle (bursting phenomenon) for smooth flow are: the dimensionless bursting period $T^+ = \frac{TU_\infty}{\delta}$ (independent of Re) is ~5, the duration of sweeps or ejections is 1 second or less, the ratio of maximum instantaneous Reynolds stress to the averaged value is up to 60, the dimensionless spatial scales ($\lambda^+ = \frac{\lambda u_*}{\nu}$) of bursts are λ^+ ~100 laterally and 700 to 1500 longitudinally, the ratio of maximum instantaneous u_* to the averaged value is 3, the bottom pressure pattern is consistent with the burst structure, the spatial downstream extent of large coherent structures in flow is 2.5δ and the typical "eddy" scale is 0.25δ. The phenomenon is also established for rough flows but quantitative data exist only for wind tunnel experiments.

b. From <u>in-situ</u> measurements

A large time-scale intermittent Reynolds stress has been observed and an hypothesis relating scales of intermittency is proposed by

Falco (1977). For observational details see *Gordon and Witting* (1977) and *Tochko* (1978). Observed periods are 7-60 sec and durations are ~8 sec.

2. Facts Which Need To Be Known

a. From laboratory flume research

A detailed picture of the turbulence structure of rough boundary layers, especially the parameters related to the ejection-sweep cycle is needed:

(i) in equilibrium boundary layers with different types of natural roughness, including small scale bedforms,

(ii) under positive and negative pressure gradients, and

(iii) in sediment-laden rough and smooth turbulent flows.

b. From in-situ (deep sea) BBL measurements

The complete turbulence structure, especially scales and periodicity of intermittent Reynolds stress production in a hydraulically defined area should be determined. (Ignoring the lack of knowledge on rough flow scaling and depending on different model assumptions whether outer or inner variables scale the ejection-sweep cycle, periods between 50 and 200 sec might be expected for an assumed smooth deep sea bottom with a log layer of 2 m thickness and flow velocity amplitudes of 5 cm/sec.) This will make it possible to compare natural flows with laboratory simulated flows and also to test whether it is possible to parameterize the in-situ turbulence data by outer flow and hydrographic variables. This information will also yield threshold data and coefficients for long-term in-situ microprocessed flow measurements.

The phase-relationship between mean flow, turbulent kinetic energy, Reynolds stress and bottom stress for non-equilibrium flows (e.g., tides) must be sought.

Experiments to search for and identify helical flow structures should be carried out.

3. Approaches To Problems Stated In The Preceding Section

Two- and three-dimensional velocity probes and bottom stress probes are required with temporal and spatial resolution to measure the turbulence features. A vertical array of these sensors, positioned between 1 and 100 cm above a mud bed or between 10 and 100 cm above a rough bed should be deployed within an array of conventional current meters monitoring the Ekman and the mixed layer. Stereo bottom photography should define the bottom roughness. Data should be collected over several tidal cycles. For more details, see section F on interscale relationships.

Present technology and existing instrumentation which can be utilized:

(a) metal-clad hot wire anemometry; the 1, 2, 3, dimensional probes are pressure-proof to 10,000 psi and are temperature compensated. The sensing wires are of 4 mm length and 0.4 mm diameter.

(b) flush foils as bottom stress sensors (5 mm length)^2, 0.2 mm thick, in connection with anemometry.

(c) digital sea data cassette recorder system with a capacity of 17×10^6 bit per C 90 tape, writing speed 1.5 to 6×10^3 bit/s (or slower).

C. Short Term Non-Turbulent Flow Processes

Velocity variations that are short in time scale compared to the tidal period are commonly introduced into the benthic boundary layer through phenomena such as internal waves and small scale quasi two-dimensional eddies advected past the interior of the flow. These temporal variations can cause large changes in flow speed and direction relative to the long term mean or tidal currents; consequently they are of major significance in regard to sediment transport and may be very important in the feeding activities of benthic organisms. Presently, not very much is known about such features in the deep ocean, because flow sensors with suitable temporal resolution and the necessary zero or gain stability are still in the developmental stage. Moreover, the nature of these fluctuations depends very strongly on the general topography surrounding the site of interest.

Grant (1977) and *Smith* (1977) have argued that the superposition of currents with very different time scales has the net effect of raising the boundary shear stress due to each component separately as well as raising the total boundary shear stress. This non-linear interaction of the superimposed flows makes the short term non-turbulent flows of concern in this section extremely important for sediment transport and erosion even when they are relatively small in amplitude. To date, field evidence for this non-linear interaction is indirect and perhaps inconclusive. It comes mostly from shallow water experiments which shows the initial motion of sediment grains to occur at much lower mean boundary shear stresses in the presence of wind-wave velocity fields than would have been the case otherwise. Such experiments also show the episodic nature of sediment transport under such conditions. A similar effect is expected in deep water and its importance in regard to erosion and transportation of bottom materials through enhanced boundary shear stress as well as an enhanced eddy diffusion coefficient, certainly must be evaluated in regions where unsteadiness in the few minute to hour band is common.

The horizontal length scales of these fluctuations generally are large compared to the boundary layer thickness so, except in areas of abrupt topography such as deep sea furrows, they can be investigated with sufficient accuracy by measuring temporal variability at several levels from a single bottom mounted tripod. However, due to the limited vertical scale of these velocity fluctuations and their importance in regard to sediment transport, including their effect in putting bed material into suspension, the flow measurements need to be concentrated within a few tens of centimeters from the sea bed. This procedure avoids unnecessary dependence on theoretical characterization of the non-linear interaction process, hence, on potentially erroneous extrapolation of measurements made from higher levels.

If the fluctuations in this frequency band are caused by breaking internal waves then even higher turbulent levels are expected, therefore even higher boundary shear stresses and higher eddy diffusion coefficients for a given interior velocity will be produced. Such events are likely to be episodic rather than periodic in nature but may well dominate the resuspension of bottom sediments in spite of their occasional occurrence. For this reason, continuous monitoring of near bottom currents and low frequency turbulent kinetic energy values at a few levels near the bed may be essential. In the furrow areas there certainly will be a need for simultaneous measurements both inside and outside the troughs. The acoustic current meter under development by Williams (*Williams and Tochko*, 1977) is suitable for this purpose.

D. Three Hours to Three Days

On time scale of 3 hours-3 days, the benthic boundary layer (BBL) is quite variable. Part of this variability is due to tidal currents and inertial currents and the magnitude of the oscillations is comparable with the geostrophic currents. Further variability is associated with downward propagating internal gravity waves originating above the BBL and interfacial gravity waves formed at the top of the mixed layer. Breaking of these internal waves in turn creates other variability which may have time scales in this range.

In the proposed regions to be studied the thickness of the BBL is expected to be of order 100 m and variable over these time scales. Thus in the 3-day experiment, sampling in the vertical and in time must be such as to resolve these changes. As the possible sites are on the sloping lower continental rise, horizontal advective processes are enhanced. Such processes can be expected on these time scales and may be due to tidal oscillations and/or changes in the mesoscale field. During the 3-day experiment hydrographic and nephel transects should be made cross-stream and up/down stream on scales of 100 km to help identify if these processes have occurred during the experiment.

The gross structure of the BBL and its variability over these time scales is important and easily measured with VACMS, transmissometers, CTD's etc. However, the most intriguing regions are those near the top and bottom of this layer. Instabilities occurring at the upper region may be important in determining mixing processes here. Instruments to measure the variability over these time scales, to supplement CTD data, need to be developed. Visual tracers offer a possible technique to measure this variability.

The region nearest the bottom, the so-called inner region, is the region of most general interest. It is here where the turbulent intensities are highest and where the water and bottom interact. Fortunately, instrumentation is available to measure the turbulent fluctuations down to about 50 Hz at several layers in this region (BASS system and hot wire probes). It is crucial to determine how these fluctuations and their stable averages, the Reynolds stresses, vary over several tidal cycles in order to attempt to relate these inner variables to external parameters. It is important to have time-sequence stereo bottom photographs to relate bedform migrations and suspended load transport to these measurements of Reynolds stresses. It is important to compare the bottom shear stresses inferred from these measurements with those determined by traditional, mean speed profilers, as well as those determined by stress meters.

The 3-day experiment is exceedingly important. It is to be a comprehensive study aimed at obtaining a definitive data-set helpful in testing concepts and models. Results from this study will be essential in designing the six-month experiment. It may tell us, for example, that it may be necessary to sample the high resolution speed probes only 10% of the time to obtain meaningful estimates. Sediment concentration profiles will enable us to estimate whether they may dynamically influence the flow field in the BBL.

E. Greater Than Three Days

Evidence for the ubiquitous occurrence of bottom mixed layers of limited vertical extent exists. Our goal must now be to understand the role such layers have on deep ocean mixing. These layers form at all isopycnal levels in the deep ocean and in conjunction with along-isopycnal advection are a mixing mechanism of the deep ocean. The relative roles of mixing and advection along isopycnal surfaces, and this boundary-produced vertical flux is unclear.

Experiments to sort these roles out will require measurements longer than the mesoscale time scale of the site (e.g., eddies and bottom-trapped waves), usually months. The site itself should take advantage of the use of non-decaying conservative inputs e.g., Θ, S, anomalies. These should be monitored on a yearly time scale. An experiment designed to look at the evolution of mixed layers formed at an abrupt topographic influence, e.g., seamount or large dunes, record samples at a time scale governed by the length scale of detached mixed layers and the advection velocity e.g., minutes, should be undertaken.

F. Interscale Relationships

The action of the turbulent boundary on the bottom sediment is sometimes thought to be through small-scale structures associated with the bursting phenomenon. Investigation of this process requires that velocity measurements with small, fast probes be coupled with observations of sediment behavior. In this way, sediment motions and resulting bedforms can be related to the hydrodynamics of the small scale turbulent structures near the bed. Because of the difficulty inherent in this type of investigation, it is best performed in the laboratory.

For the results of these laboratory experiments to be applied usefully in the deep-sea boundary layer, we need to be able to parameterize the relevant small-scale near-bottom hydrodynamic parameters, for example $(\overline{uw})_{max}$, in terms of the outer scale variables: $U_\infty(t)$, $p(t)$, f, and bottom topography. Also we need to confirm that the laboratory derived "bottom turbulence/sediment behavior" relationships apply in the field environment.

To accomplish these tasks, an experiment with a duration of several tidal cycles, (henceforth called the "3-day experiment") should be performed, in which the outer variables, bottom turbulence and sediment behavior are all monitored.

Recently, small (1 cm), fast (>10 Hz) velocity probes capable of operating in the deep sea have been developed. In the 3-day experiment the vector velocity structure near the sea bed should be recorded at a rate that does not degrade the frequency response of the probes. A time lapse stereo camera system will be used to record sediment behavior, and also the positions of the velocity probes relative to bedform features. A conventional current meter (e.g., VACM) will be used to record the outer flow (U_∞), and additional current meters of this type at intermediate levels will be valuable in guiding us to the correct analytical model for the parameterization. The density field will be monitored with CTD hydrocasts during the course of the experiment. Microtopography will be determined from the stereo camera images, and larger scale topography from PDF records and/or deep-tow survey data. Sediment box-cores from the site will be retrieved for analysis including insertion in a laboratory flume.

Combining the field derived "outerflow/bottom turbulence" relationship with the laboratory derived "bottom turbulence/sediment behavior" relationship gives an "outerflow/sediment behavior" that can be compared with observations from the 6-month experiment. (If in the 3-day experiment no bottom sediment motions are observed, field confirmation of the laboratory "bottom turbulence/sediment behavior" relationships may be postponsed to the 6-month experiment.)

G. Physical Oceanographic Considerations in Flow Boundary Interaction

Let us assume a rough wall of non-uniform, irregularly spaced bed features being modified.

1. We presently know, or will know from the laboratory phase:

(a) the scaling of stress production in terms of mean flow parameters,

(b) vertical profiles of velocity and turbulence characteristics, as modified by suspended load, but only for steady flow,

(c) microtopography, which is a spaced roughness (e.g. crag-and-tail) that affects boundary layer profiles and turbulence characteristics. Scaling lengths to describe such features will be derived in the laboratory.

2. We don't know, but must investigate in the 3-day experiment:

(a) The effect of unsteadiness, internal wave down to tidal frequency, on the time scales of motion of suspended material; i.e., lag-time of deposition and response time of cohesive sediments to critical stresses.

(b) Validation of laboratory models of rough wall scaling parameters.

3. We cannot examine with the necessary precision:

(a) the vertical or lateral structure of turbulence in a suspended sediment-laden flow over a mobile boundary.

(b) changes in total boundary stress due to bottom sediment movement--maybe a critical parameter in biological studies.

4. We must:

(a) attempt to characterize the measurement period, or periods within it, in relation to the laboratory experiments on sediment motion,

(b) examine the lateral spatial flow inhomogeneities as a control on the laboratory experiments and the three-dimensional coherent boundary layer eddies,

(c) test scaling parameters from laboratory characterization of stress generating events,

(d) establish time scales for magnitudes of "critical sediment transport" variables for input to six-month experiment,

(e) validate length scaling of roughness in relation to flow for input to boundary layer models.

APPENDIX II. NEPHELOMETRY

Chairman: I. N. McCave

Rapporteur: J.R.V. Zaneveld

Participants: P. Biscaye
W. Gardner
S. McLean
J. Milliman
M. J. Richardson

A. Basic Questions

1. Distribution of the concentration and nature of suspended particulate matter (spm) in both time and space.

2. Variation in size and settling velocity distributions as a function of height above the bed.

3. Residence time of suspended matter as a function of size/settling velocity in the nepheloid layer; How far does the spm get transported?

4. What are the causes of the nepheloid layers?

5. Presuming that a probable cause of nepheloid layers is bottom erosion, what is the frequency in time and space of erosional events?

B. Concentration

There are two basic methods for the determination of the concentration of spm: optics and gravimetry. It may in the future be possible to determine low concentrations of spm by acoustic techniques, but these are not yet developed for use in the 10-100 μg/l range.

Of the two principal optical methods, scattering and transmission, the latter lends itself better to long term measurements as it has lower power requirements, is simpler in optical construction, and the measurement can readily be related theoretically to particle properties. Transmission can be as sensitive a measurement as scattering because the beam attenuation coefficient includes the total scattering coefficient which is the integral of light scattered at all angles. Furthermore, a transmissometer can be absolutely calibrated. A light source with low power consumption that can be used in a transmissometer is a light emitting diode.

A transmissometer can be constructed with a relatively small sampling volume so that it measures smaller particles only with the signal of the larger particle, appearing as spikes, which can be ignored. By using a large sampling volume (greater beam width) the

observed transmission would include attenuation due to the larger particles. By subtraction of the two signals one may then obtain relative abundances of small and large particles. This would be useful in the observation of large particles closer to the bed, and small particles which may act as a quasi-conservative tracer of layers.

A gravimetric calibration of the optics is desirable. This would be best done by in-situ filtration; however, in order to obtain more gravimetric and optical data of varied concentrations, collection of water samples using a rosette sampler in conjunction with the optical system would be a less expensive and more efficient method. In-situ filtration would be desirable both for calibration and for collection of samples of spm for subsequent scanning electron microscopy, x-ray diffraction and chemical analysis. The latter data may be of use in tracing particles and also of use to biologists concerned with benthic particle production. Because the large particles are relatively rare, it may be necessary to use larger pore-sized filters in order to obtain sufficient sample volumes. Another useful technique to obtain samples of large particles is use of sediment traps.

Distribution in both space and time of the concentration and nature of spm, as determined by the above optical methods, would be accomplished by use of the instruments on the cyclosondes as outlined in the six-month experiment section.

C. Size and Settling Velocity

The sizes of fine particles from the deep sea may be measured by means of a resistive pulse (Coulter) counter or by visual sizing of magnified images of filters. We do not think that either category of information actually reflects the true size distribution of particles in the deep sea as the Coulter counter destroys the large fragile particles and with visual counting it is difficult to obtain statistically reliable information on the smaller particles. Therefore we do not suggest the adoption of a Coulter counter for in-situ use.

The settling velocity distribution is a more useful parameter in dynamical calculations of nepheloid layer behavior. It is very difficult to measure. We envisage three possibilities, all of which involve lowering a bottle into the nepheloid layer and closing it. Sediment is allowed to settle in the bottle. In one scheme, after a preset time, the bottle is divided internally into a number of segments, the contents of each segment would be filtered and weighed. The second and third schemes involve monitoring the changing concentration distribution with height in the bottle by means of either a transmissometer racked up and down or a range-gated acoustic sensor in the top of the bottle. Determination of the settling velocity distribution as a function of height above the bed could be made by a vertical array of these devices.

D. Residence Time and Transportation

If a source of distinctive particles (of natural or introduced origin) could be located in a restricted erosional area of the sea bed, they could be used as a tracer and their distribution downstream in the bed and in suspension would yield the distance of transportation, and, if the current velocity is known, would also yield the residence time. We have in mind either radioactive tracers, natural chemical tracers, or particles of biological origin.

E. Causes of Nepheloid Layers

Possible causes of nepheloid layers are direct transport of spm from the continental margins as either turbidity currents, the fine fraction of which may contribute to nepheloid layers, or by leakage of fine sediments from continental shelf areas in the form of low speed gravity driven flows down submarine canyons. A second class of generation mechanisms of nepheloid layers is erosion of the deep sea floor. The temporal and spatial scales of this erosion are unknown, but that it occurs is demonstrated by many bottom photographs.

F. Erosional Events

Based on the above presumption we wish to know when and where nepheloid layers are generated. In-situ flume experiments should indicate the current velocity levels required to produce erosion and the rate of erosion.

Two models suggest themselves to us; firstly, that erosion may be concentrated in "benthic storms", i.e., large scale highly energetic events of limited duration, and secondly, more uniformly distributed events of smaller scale and duration occurring over a larger space and time scale. Large scale events may advect through monitoring stations and be detected by their velocity and optical signal as a function of time. Detection of a single smaller event would be more difficult but a uniformity of the signals over large periods of time could suggest many small-scale erosional events.

APPENDIX III. BED MORPHOLOGY

Chairman: C. D. Hollister

Rapporteur: P. F. Lonsdale

Participants: M. Miller, P. Paluzzi, R. Sternberg, B. Tucholke

The group reviewed what we know, think we know, or guess, to be the types and dimensions of sea bed morphology likely to be encountered in a HEBBLE area. We considered, for each type of bedform, which techniques would be most applicable for mapping and measuring, whether there was any potential for observing active migration, and if so, how. We then went on to frame some general questions about bedforms that a HEBBLE could help answer, and a few specific hypotheses that could be tested.

A. Bedforms

We first feel obliged to offer our present best guesses on the nature of each type of bedform, not as a display of our ignorance but as an interim guide to biologists, hydrodynamicists, etc. who may be planning *in-situ* experiments. Discussion was restricted to bedforms known to exist on a cohesive substrate in the western North Atlantic. In order of increasing size:

(1) very fine lineations on an otherwise smooth bed, with heights of less than 1 cm, apparently parallel to the prevailing flow. The distribution of these subtle grooves is poorly known because they are so difficult to discern, but they are often seen in close-up examination of current swept areas perhaps developed in a homogenous bed, but more likely resulting from "streaking" downstream of minor obstructions.

(2) "crag-and-tail"--low (1-10 cm) streamlined ridges of mud extending downstream as drifts in the lee of obstacles. The obstacles may be small pebbles that are exotic to the BBL (e.g., glacial erratics), burrow mounds, or excrement dumped on the bed. It appears that these features have the random scatter of the causative obstructions, though it is possible that they have organized patterns, and might be developed on a homogenous bed. Perhaps they are merely slightly larger variants of Type 1.

(3) transverse, generally asymmetric ripples, generally 1-2 cm in height and 20-50 cm in wavelength.

(4) sharp-crested ripples, believed to be longitudinal, with heights of 10-20 cm and wavelengths of 1-2 m.

(5) small furrows, elongate troughs with depths of 1-2 m, widths of 1-4 m, lengths of up to several kilometers, and spacings of 100-200 m oriented parallel to the flow.

(6) Other larger scale bedforms, including large furrows (10-20 m wide and deep) and mud waves (20-100 m high, 1-2 km wavelength) were mentioned but not discussed further because they seem unsuitable targets for HEBBLE, though they are candidates for detailed hydrographic and current meter survey.

B. Mapping Techniques

Type 1 bedforms can only be observed by close-up low-angle oblique photography, imaging an area of about 1 square meter per frame, or from a submersible. Consequently, it is not practicable to examine these features over a wide area.

Type 2 and 3 can be resolved on large area (e.g. 10 x 10 m) photos, and their distribution can be plotted from photo mosaics. Application of stereographic techniques to deep tow photos could yield contour maps at a vertical interval of 1 cm. They are not big enough for individuals to be displayed on side scan sonar records (at a search rate several orders of magnitude greater than any photo technique), but variations in population size or density might possibly be perceptible on side-scan records as a change in the back-scattered signal.

Type 4 ripples are barely visible on side-scan records. Bottom photos would be needed to accurately measure size and trends, but side-scan could show presence or absence.

Type 5 have gross morphologies that are well displayed on side-scan. Selective bottom photography would be needed to obtain details of furrow and interfurrow morphology.

C. Bedform Mobility

Time lapse photography offers some prospects of sensing a change in morphology because of sediment transport for types 1-4, with a general feeling that the smaller the feature the more likely it is to move. If movement is discernible over reasonable lengths of time (6 months), then this measurement would be most valuable for classes 3 and 4, where migration of individuals in a ripple field could be studied.

Type 5 may show changes in pattern over a 6 month or 3 year period that could most profitably be examined by a repeat side-scan sonar survey. Also, the walls and floors of active furrows, which sometimes have ripples, are perhaps the most rapidly changing sites on the deep sea floor, at a scale that could be examined with time-lapse photography.

D. Distribution

Types 1 and 2 are thought to be widespread. Type 3 ripples have been found in several places, but in all instances they cover only tiny patches, a few square meters of the sea floor. We know of no extensive patches, uniformly rippled for several hundred m^2 that would be good HEBBLE candidates, and we suggest that participants' attention be diverted from this class of feature. The exceptional case, a site where we can predict the presence of transverse ripples, is on the sloping walls of furrows.

Type 4 ripples have been found in few areas, but in patches of large extent. We know of one such field that covers several km^2 of the plain at the foot of the Blake-Bahama Outer Ridge. Should it be decided that this type of bedform is worth HEBBLE study, then this would be a suitable site.

Type 5 furrows probably have an extensive distribution, at least below the southern parts of the WBUC.

E. Questions of Interest About Bed Morphology

(1) Their origin

(2) Are they in equilibrium with present currents?

(3) If so, can we learn which factors of the BBL control their distribution, so that we can use their presence to make predictions of the flow in areas lacking physical oceanographic measurements?

It was felt that answers to these questions were particularly needed for class 4 and 5.

F. Some Hypotheses to be Tested

(1) In the deep sea, transverse bedforms are mainly developed by traction load of non-cohesive sediment; longitudinal bedforms are characteristic of suspended load transport. The implication would be that type 3 ripples are in fact made of non-cohesive aggregates of biologic origins.

(2) Type 4 ripples are oriented parallel to the flow direction near the bottom of the Ekman layer.

(3) Type 5 furrows are thought to be created by a helical secondary circulation. They occur where measured free flow is very steady in direction. A large proportion, over 50%, of the near-bottom water and suspended matter transport, occurs over the furrows, though they account for less than 1% of the bed area; fluxes are very much less over the interfurrow strips. Large objects (large dead animals, seaweed, current meters, for example) falling through the BBL are moved laterally by the secondary circulation, and preferentially deposited in the furrows.

APPENDIX IV. BIOLOGICAL/BED INTERACTIONS

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Those sediments which are eroded and transported are made less cohesive and therefore more erodible by organism reworking.

A. Introduction

To determine the common biological/sea floor characteristics of the high-energy study region and how they differ from surrounding areas of comparatively low energy with "stable" beds, an intensive sampling program will have to be initiated using box cores supplemented in some instances by 3-meter long large diameter gravity cores both upstream and downstream from the site, and cross stream to points outside the zone of erosion. Biological, chemical, geotechnical, and geological properties will need to be determined. Several separate samples will be obtained of the uppermost sediments for laboratory flume studies.

Therefore the site must be comprehensively surveyed with regard to:

(i) morphology of bedforms (i.e. using photography, stereo-TV, side-scan sonar),

(ii) life position and trophic components of the identifiable benthos,

(iii) depth of sediment reworking by organisms (as measured by ultrasonics, radioactive tracers in box cores, interface camera, photography, x-radiographs),

(iv) geotechnical acoustic properties (compressional and shear wave velocities and attenuations parameters).

All of the above measurements can be made by coordinated survey with precisely navigated box cores, deep-tow surveys and submersible operations. Details of site surveying can be found in the sections on that subject in the main body of the report. However details concerning biological interaction with geotechnical properties are outlined below.

B. Box Core Studies

1. Biological

All size, life position, and trophic components of the benthos will be determined from box cores including meio-, macro-, and microorganisms. Rates of sediment reworking (mixing) by infauna will be determined using lead-210 distribution with depth in the core.

2. Chemical

Quantities of mucopolysaccharides will be measured. It is most important to quantify levels of sediment binding of mucopolysaccharides in the topmost sediment layer (0.5 cm).

3. Physical, Geotechnical, Acoustic

The bulk properties of the sediments will be determined on samples from the surface and below the sediment-water interface in these cores. To provide a common link to the non-destructive acoustic testing carried out in the lab and the in-situ experiments, measurements will be made of compressional and shear wave velocity and of the reflectivity of the sediment-water interface. From these data calculations can be made of the variations of density, bulk modulus, and shear modulus at the sediment water interface.

The shear strength of the sediment-water interface may prove to be a quantitative measure of the erodibility of these sediments and therefore vane shear and triaxial shear strength measurements will be made.

The stress history of the sediment may have a strong influence on erosion of deep-sea sediments. For example, sediments which exhibit strong, overconsolidation may require a significantly higher critical bed shear stress before erosion occurs than would an underconsolidated sediment. Samples will therefore be taken for consolidation and triaxial compression measurements.

It should be noted that an outgrowth of the coupling of these measurements with the suite of chemical, geological, and especially biological parameters should lead to a much better understanding of the factors controlling geotechnical, acoustic, and physical properties of the upper meter of sediment. It is possible that individual grains may be bound together by inorganically precipitated cementing agents. The most likely cement is calcium carbonate. The microscopic, SEM and electron-probe observations of this zone should reveal its presence. Organic carbon and nitrogen will be measured for correlation with organic standing stocks.

4. Geological

The texture of the sediments at and below the sediment-water interface may have primary influence in the erodibility of sediments; however, since the key element may be the presence of a layer of fecal pellets and other organic mineral aggregates which gradually compact with depth into massively bedded sediments, measurements of texture which tend to disaggregate these pellets should be avoided. Gentle wet-sieving, direct measurements using light microscopy, the SEM, and perhaps the Coulter counter all will serve in different ways to characterize the size distribution and aggregation of the sediments.

The physico-chemical bonding that exists between clay minerals and also between clay minerals and organic particles play an important role in binding the sediments. Since each clay mineral type has a tendency to bind with differing degrees to others, it is important to have a quantitative measurement of the percentages of the various clay minerals.

Primary sedimentary structures within the sediments carry some information as to the history of the average flow regime. Sections of the box core can be examined visually and with x-ray radiographs to describe these structures.

The sedimentary history at the site may carry with it information as to the stability of the flow regime and stability of sediment supply and characteristics; all of which carry implication as to the stress history of the sediments. The above suite of measurements taken in concert with Pb^{210}, C^{14}, δO^{18}, carbonate, and micropaleontological estimates of age with depth will help determine whether sedimentation has been constant at or nearby the site. It should be noted that it is expected that the box cores will be supplemented with 3 m long gravity cores for this phase of the work since it is important to examine the stress history of the sediment column to significant depths.

C. In-Situ Measurements

1. Temporal Monitoring

The objective of temporal monitoring is to extend characterization measurements over periods of time governed by phenomena that are short-term, periodic, and long-term, periodic, as well as aperiodic. Implicit restrictions on such monitoring are in power requirements, costs, and logistics. Measurements of rates of processes are largely dependent upon frequency of sampling. Sampling schemes must incorporate periodic measurements predetermined with regard to "best-guess" estimates of phenomena in question as well as aperiodic measurements either predetermined or conditional. Artifically, the time frames of the above monitoring can be separated into three-day and six-month experiments. The geotechnical properties to be measured will be outlined first.

(a) Geotechnical properties

Both direct measurement techniques and nondestructive methods should be considered for measurement of pertinent physical properties of the upper 0-20 cm sediments. The critical geotechnical material parameter is probably the shear strength but other related properties can be used as indicators of sediment disruption and movement. Traction stresses at the sediment-water interface will be reflected into the sediment bed in the form of shear stresses, and it is therefore desirable to measure these induced shear stresses.

(i) Shear strength. The undrained shear strength can be measured directly with a vane device or cone penetrometer. A small vane shear apparatus (2 mm vane) has been developed for use with soft cohesive sediments in the laboratory. This device can be modified for <u>in-situ</u> measurements of the upper few centimeters. Since there is some amount of disruption to the sediments, only a limited number of such measurements should be taken at experimental sites at selected time intervals in selected positions.

New techniques for in-situ measurement of shear strength of the upper few millimeters should be considered. One possibility is to measure traction stresses required to initiate motion of a small flat, rough plate in contact with the sediment surface.

(ii) Differential pore water pressures. Initiation of shear deformations within the sediment bed will cause changes in pore water stresses. It is likely that these changes will be very small and therefore it may be necessary to increase the sensitivity of existing transducers. The concept is to imbed a small pore pressure probe in the sediment which measures on a pre-selected or conditional basis the pressure variations on both sides of the sediment-water interface.

(iii) Non-destructive measurements. Other techniques which are identified as possible means of monitoring sediment properties and behavior are:

Reflectivity and compressional wave velocity: acoustic measurements of surface reflectivity and compressional wave velocity can be used to discern changes in acoustic impedance.

Shear wave velocity: surface shear waves can be generated and speeds measured in the upper few millimeters to determine changes in shear modulus and hence changes in shear strength.

Ultrasound: the sediment bed can be insonified with an ultrasonic scanner to look at the upper few centimeters. It should be possible to relate the energy dissipation to physical properties such as density and porosity.

Gamma-ray attenuation: gamma-ray attenuation measurements can be used to determine density and porosity of the sediments. These measurements coupled with physical property measurements on recovered samples will be useful in studying erodibility.

(b) Three-day monitoring

The three-day monitoring effort is centered around an instrument tripod resting on the sea floor emplaced and retrieved by submersible or by a free-fall package which can be recalled acoustically.

Each tripod would be equipped with time lapse photography using stereo pairs. The area of sea floor within the field of shooting is one meter square. The area is restricted because high resolution is required to view individual particle movements on and immediately above the sea floor. The rate of shooting must be determined by velocities of near-bottom flow as measured in the oceanographic survey done in conjunction with the sea floor survey. One best guess in flows ranging from 10 to 30 cm/sec would be to shoot for 10 seconds every 10 minutes. Specific observations of the sea bed itself are rates of movements of ripples and rates of formation and erosion and/or infilling of mounds and scours. High frequency measurements as suggested are needed to monitor movements of epifauna and infauna. Effects of deposit-feeding invertebrates in terms of fecal-pellet production, active "ejections" of fecal material into the overlying water column and microstructural changes of the sediment surface (i.e., ichnological features such as trails, tracks and mounds are of special note).

One potential complication which is to be expected in high-energy benthic boundary layer environments is the attraction of the instrumented tripod to active predators such as demersal fishes and decapod crustaceans. These animals may profoundly promote erosion and produce microtopographic features through their active feeding movements. In order to fully document such effects it would be extremely useful to incorporate conditional shooting of the camera when such animals move into the field.

(c) Six-month monitoring

The six-month monitoring effort should follow the three-day monitoring effort. Little is known at present about what long-term changes may be expected in sedimentary parameters due to organisms.

At a minimum, time lapse photography using stereo-pairs should be used coupled with water velocity and light transmission measurements. The use of traps over the long-term would be of dubious value due to qualitatively and quantitatively induced changes in the trapped material and fouling organisms on the tripod itself which would accelerate depositional rates.

The frequency of taking photographs should be directed to longer term formation and disruption of biogenic features, such as burrow- and tube-building. The six-month period may embrace the period of larval settling, metamorphosis, growth and establishment of opportunistic benthic invertebrates.

Long term change in geotechnical properties of the sediment may be expected within the time frame of the six-month experiment. Therefore, periodic measurements of sediment elastic properties would be extremely useful, such as compressional and shear wave velocities and attenuation via microprobes. These acoustic measurements along with a density measurement via ultrasonics would enable one to determine all major geotechnical properties with time.

2. Experiments

(a) Biological

The basic device for these experiments will be the free-vehicle and/or submersible deployed corers with injection capabilities developed by K. L. Smith. These devices will be modified to inject exotic particles into the core and to provide carefully controlled mixing rates in the water overlying the sediment core. Exotic (i.e. easily identifiable) particles of closely controlled characteristic (e.g. size, shape, specific gravity) will be injected into the corer at pre-programmed times. Suspended fractions can be sampled at selected times after their introduction. With an injection of metabolic poisons biological activity can be stopped after given intervals to quantify the following particle-specific rates.

(i) Biodeposition (removal of particulates from suspension or, conversely their net introduction to the bed);

(ii) Depth-specific mixing;

(iii) Incorporation into tubes and other cohesive matrices;

(iv) Particle feeding by deposit feeders;

(v) Pelletization;

(vi) Bacterial colonization;

(vii) Bacterial removal by digestion.

Appropriate sampling intervals will be estimated from initial time-lapse photography of the three-day experiment.

Suitable controls are cores poisoned at the outset of the experiment. The great advantage of this methodology is that the corer recovers the organisms responsible for these activities, thus making the information gained generalizable to areas of similar faunal composition, and aiding in the selection of organisms for the biological laboratory experiments.

Particle selection for these experiments will be based upon characteristics of particles on and near (<10 cm) the bed. These characterizations will in part be provided by other disciplinary subgroups of HEBBLE.

(b) Inverted flume

Along with measurements of bottom shear stresses, initiation of particle motion, and erosion thresholds, samples should be taken both outboard of the flume to characterize ambient fauna and surface sediments and inside the flume after the imposed erosion to characterize the remaining surface and biota (i.e., to determine whether only the pelletized fecal layer has been eroded). During the flume experiments, interface or low-angle photographs will be used to estimate the importance of organisms particle injections into the water column. This role will also be estimated by anesthetization of the fauna under the flume before a subset of the experimental runs. Anesthetization would be facilitated by the use of a recirculating flume. These runs should encompass velocities encountered during the six-month monitoring.

(c) Field tracers

To test predictions from both the injection and flume studies as well as from the laboratory flume work under natural field conditions, exotic particles will be emplaced on the sea bed in known amounts at known locations (*Self* and *Jumars*, ms.). Cores taken at several times and at various distances from the site of emplacement will reveal lateral and vertical dispersion patterns of the tracer and which organisms have been involved. It will be useful to compare the mixing rates determined from these and the other in-situ experiments with mixing estimates from isotopic measurements in box core samples. Selection of a suitable tracer will be based upon results from the injecting corer experiments and particle characterizations provided by the other disciplinary groups of HEBBLE. The experiments will also require precise bottom-relative navigation.

(d) Manipulative experiments

The in-situ geotechnical parameters and responses to be measured in the manipulative field experiments will be basically the same as those discussed for the monitoring effort. However, the vane shear measurements will probably be more limited in that measurements will only be made prior to and immediately after the experiment. Since the

flow regime and sediment bed is restricted, it should be possible to devise a sensor arrangement so that continuous monitoring of the other parameters can be made (i.e. reflectivity, compressional wave, shear wave, ultrasound, gamma-ray). Shear stresses and pore pressures should also be continuously monitored.

(e) Other experiments

Experiments should be designed to fit in with those of the physical oceanography group. The manipulative experiment would be coupled with in-situ temporal monitoring efforts on a similar or the same area.

Instrumental tripod packages would be used as discussed earlier. Manipulations for various parameters may provide new and unique insight into processes not readily understood by monitoring alone. These would provide rate functions for modeling efforts. Some suggested manipulations to be incorporated into the three-day and six-month monitoring framework and instrumentation follow:

(i) Three-day experiment. In order to measure rates and pattern of turbulent flow over the sea bed within field of stereo-pairs discussed above, fluorescent dye should be introduced at 1 cm intervals above the sediment-water interface to 10 cm. Neutrally buoyant particles may also be introduced at the sea bed within field of view. Exotic particles of differing shapes, sizes, and densities introduced at the sediment-water interface would provide information concerning erosion, position and burial.

(ii) Six-month experiment. If a new bedform may be created via disruption or homogenization of surface sediments, (performed from a submersible such as ALVIN), subsequent recolonization by organism, and production of biogenic features and pelletization of surface sediments could be measured over time via combinations of photography and acoustic measurements as discussed above. Erosional and depositional features produced or affected by organisms can be best measured by non-destructive means.

D. Laboratory Measurements

1. Monitoring Efforts, Non-Manipulative (Undisturbed)

Undisturbed sections of the deep sea sediment will be placed in a flume with as little disturbance as possible and subjected to a series of flow experiments. In order to relate the results to in-situ experiments it is important to measure all the pertinent physical properties as well as to monitor the behavior of the sediments during the experiments. In addition, some of the in-situ instruments can be bested and calibrated during these experiments. Some of the geotechnical properties and responses are listed here.

(a) Shear strength (vane shear)

(b) Index properties; i.e. grain size, mineralogy, Atterberg limits

(c) Physical properties; i.e., water content, porosity, density

(d) Sediment microstructure (fabric) using SEM, TEM, etc.

(e) Non-destructive measurements: compressional and shear wave velocity, reflectivity, gamma-ray attenuation, ultrasound profiles

(f) Shear stress and pore water pressure (within sediment layer).

2. Manipulative (Biological)

These studies are designed to assess the importance of biological sediment binding and sediment reworking to the stability or erodibility of the sediment-water interface. Even though deep sea macrofauna can be recovered and maintained in the laboratory, there is serious question as to whether their physiological behavior has been affected. Bacterial populations and densities do appear to be altered once sediments are removed from the deep sea and it is likely that metabolic activity including production and destruction of binding agents are changed. Therefore, at this time, we suggest that it would be most productive to examine and evaluate binding and sediment reworking in nearshore sediments of similar grain characteristics where we can find organisms, especially macrobenthos of similar size and functional group to deep sea fauna in the study area.

One major difference between deep sea and nearshore bottoms which may be significant is the variation in organic matter both in quantity and quality. Recent models, for example, suggest that feeding rates of deposit feeders will depend on sediment organic content. This is something which will have to be considered in relating the results of lab experiments to deep sea processes. In order to determine what reasonable current velocities should be used in lab flume studies we need basic flow statistics from field measurements.

Manipulation will involve inhibiting reworking activity and mucus or tube (polychaete, amphipod) binding in box cores or natural sediment. The resulting change in T_c (critical erosion shear stress) will be measured with the laboratory flume. One way to evaluate the relative importance of binding and sediment reworking is to compare temporal changes to a standard critical erosion measurement of replicate box cores in which all organism activity has been stopped and all surface biogenic features have been eliminated.

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THE HEBBLE REPORT: BEING THE PROCEEDINGS OF THE WORKSHOP ON A HIGH ENERGY BENTHIC BOUNDARY LAYER EXPERIMENT HELD AT THE KEYSTONE CENTER FOR CONTINUING EDUCATION, KEYSTONE, COLORADO, MARCH 13-17, 1978 by I. N. McCave, C. D. Hollister and T. E. Pyle. 79 pages. July 1978. Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004.

A workshop was held March 13-17, 1978 on a High Energy Benthic Boundary Layer Experiment. The meeting followed recognition of the importance of high speed currents at the deep ocean bed in eroding, transporting and depositing sediments and in producing bedforms. The importance of the turbulence and turbulent mixing processes in these regions was also emphasized. The workshop proposed an experiment with three main phases, detailed survey and site selection, short (3-day), and long (6-month) experimental deployment of instrument packages designed to recover current, turbulence, optical, acoustic and photographic data. The site survey phase would involve not only hydrographic, echosounding and deep-tow survey but also recovery of undisturbed bottom samples and investigation of their properties in laboratory flumes. The short experiments would run at a high rate of data acquisition and get data on short term fluctuations of the floor and bed. The long experiments would have slower rates of data acquisition and employ in-situ processing and compaction of information from sensors. A cyclosonde profiling the lower-most 300 m of the water column with CTD, velocity and optical probes would be an essential feature. This and other aspects of the proposed program would require considerable engineering work in development of sea-bed instrument arrays.

1. Benthic boundary layer
2. Workshop report
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